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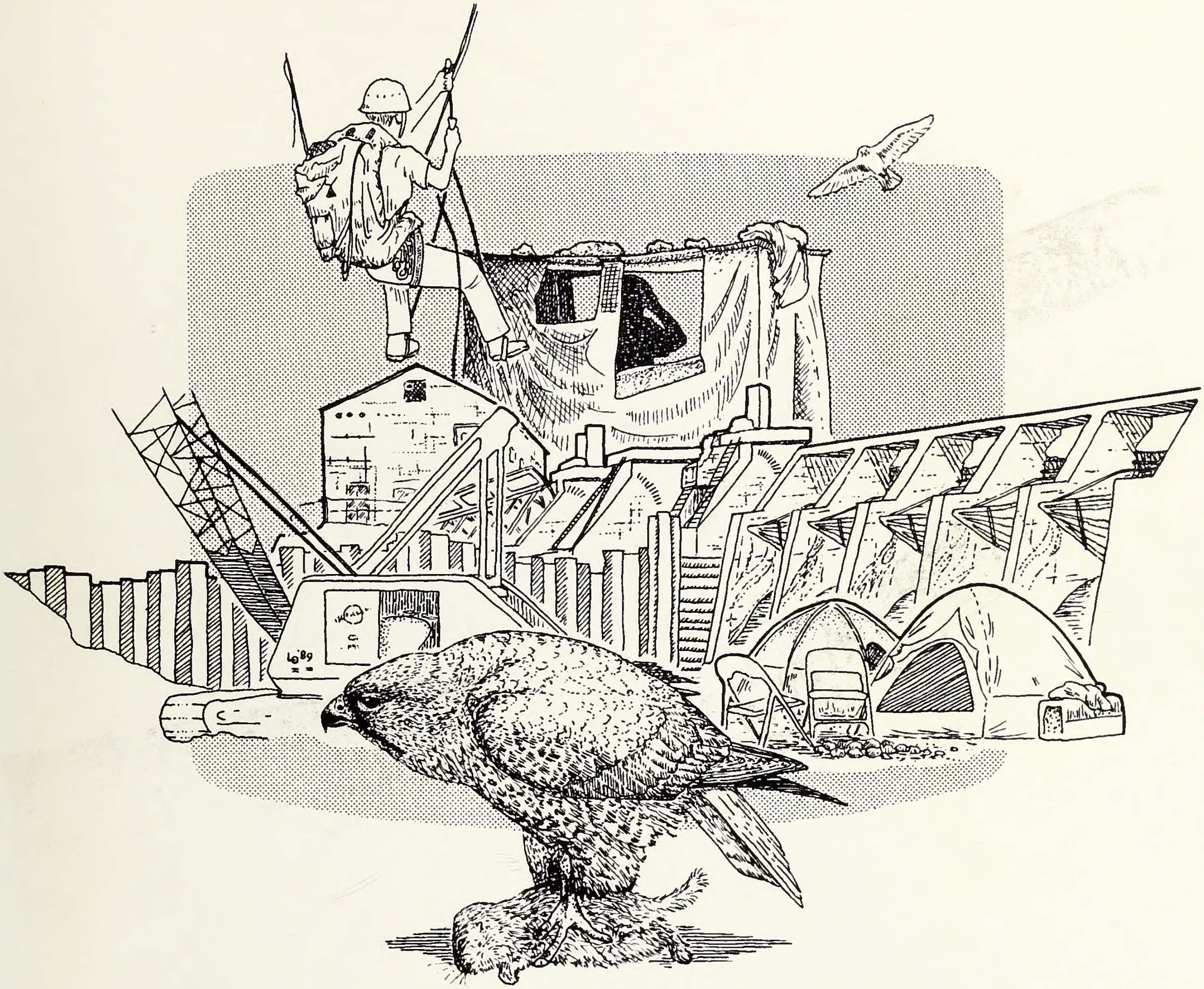

Anthonie M.A. Holthuijzen

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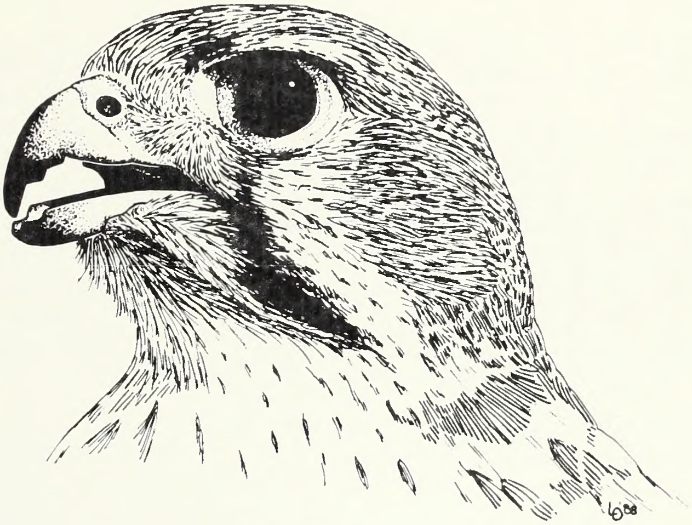

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Anthonie M.A. Holthuijzen
Idaho Power Co.
P.O. Box 70
Boise, Idaho 83707

August 1989

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Swan Falls Dam

Final Report

Anthony M.A. Holthuijzen
Idaho Power Co.
P.O. Box 70
Boise, Idaho 83707

August [illegible]

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Illustrations prepared by L. Oosterhuis © 1989

Executive Summary

This report summarizes the results of investigations from 1984 to 1987 sponsored jointly by Idaho Power Company, the Bureau of Land Management and Pacific Gas and Electric Company. The study was initiated in 1984 to evaluate the potential effects of construction activities on nesting prairie falcons at the Swan Falls Dam hydroelectric power plant located in the Snake River Birds of Prey Area (BOPA). The study had 2 objectives: (1) to evaluate the possible effects of construction and recreational activities on the behavior and productivity of nesting prairie falcons, and (2) to formulate management guidelines for nesting prairie falcons exposed to human activities.

Construction activities at Swan Falls Dam occurred from 1983 to 1986. In 1983-1984, an existing unpaved road leading down into the canyon was rebuilt. In May 1985, construction activities at the spillway started. In 1986, heavy construction continued throughout the nesting season. Possible latent effects of construction were evaluated in 1987.

Productivity has most often been used to evaluate the effects of human activities on nesting raptors; subtle behavioral changes that may have long-term consequences on raptors have not been evaluated. In this study, the entire behavioral repertoire was examined and correlated with variables measuring construction and recreational activities. The study involved detailed, continuous observations of the behavior of nesting prairie falcons. Observations were made at nesting territories within 1000 m of Swan Falls Dam (construction study location; 1984-1987), areas heavily used by visitors (recreation study location; 1985-1987), and a control study location (1985-1987). A controlled blasting experiment was conducted outside the BOPA in 1985 (Reynolds Creek) to separate the effects of blasting from other construction activities. Each aerie in the blasting study location was exposed to 3 blasts a day (167 g ammonium nitrate; 138-146 dB) at 3-hour intervals. This blasting sequence was repeated every other day until young were 35 days old, totaling 87-92 blasts per aerie. In each of the 4 study locations, 4-6 prairie falcon nesting attempts were observed each year, totaling 54 nesting attempts from 1984 to 1987. Observations of nesting pairs began during the last week of March and the first week of April (when the falcons had selected their aeries) and continued until the young were 30-35 days old. Observations started 30 min before sunrise and were ended 30 min after sunset. A total of 632 days of observation (9,380 hours) were made (pre-incubation, 91 days; incubation, 267 days; brood-rearing, 255 days; and post-failure, 19 days). The time (minutes) spent on pre-determined behaviors by male and female falcon pairs was recorded. Frequency and duration of these behaviors were calculated for each sex for an observation day. Observation days were categorized into 6-day intervals based on the approximate stage of the nesting season and labeled by midpoints.

Productivity of nesting pairs was determined by counting the number of young that were 30 days old in each occupied territory. Surveys in the BOPA started in the second week of March; surveys in the blasting study location began in the first week of April. To determine productivity all territories were re-visited at 2-3 week intervals starting in mid-May. In 1986 and 1987, 151 nestlings were weighed, and 148 were banded. Body weight was used to determine physical condition of a falcon.

Two indexes to industrial and recreation activities were measured at or near each of the observed nesting territories: (1) traffic flows (daily number of vehicles passing traffic counters), and (2) recreation activities recorded during daily visitor surveys from late March through June. All nesting territories observed from 1984 to 1987 were ranked according to 7 human activity indexes. The ranking scores were summed per nesting territory and used in correlation analyses with falcon behaviors.

Two approaches were used to test the possible effects of human activities on prairie falcon behavior. Principal component factor analyses were used to investigate associations between human activities and the behaviors of male and female falcons nesting in the construction and recreation study locations. Stepwise discriminant analysis was used to test for differences in behavior among the study locations. Separate univariate analyses were conducted with behaviors that were considered critical to the nesting cycle and sensitive to human activities.

Behaviors of male and female falcons did not show strong and consistent relationships with the measured human activity in the construction and recreation study locations. Some associations were found, but they appeared to be more related to behavioral changes over the nesting season than to human activities. The behavioral repertoire of male and female falcons showed little differences among the 4 study locations.

Percent of the day incubating did not differ among study locations. The average duration per day that eggs were unattended differed among years and nesting pairs, but not among study locations. Percent of the day brooding decreased similarly over time among years, study locations for all years combined, and among study locations for each year.

When human activities interfere with feeding over an extended period, chick mortality may increase because of excessive weight loss or intensified sibling rivalry. Prey delivery rates and the procurement time per prey item did not differ among study locations when all years or all nesting stages were combined. The relationship between prey delivery rates and human activity was not significant.

The measures of prey procurement (prey delivery rate, prey procurement index, and out-of-canyon trips/pair/day) showed substantial differences among years. Trends were similar for all parameters and were strongest for the brood-rearing stage; 1986 and 1987 were the extremes. In 1986 prey delivery rates and prey procurement time were high, but the number of out-of-canyon trips/pair/day were low; 1987 showed opposite trends. Prey delivery rates decreased with progressively later hatch dates. Prey delivery rates and the proportion of Townsend's ground squirrels in a falcon pair's diet increased with the number of young fledged per pair. There was a strong decrease in productivity of progressively later nesting falcons.

The amount of time per day that a pair was absent from the nesting territory and unable to incubate eggs or brood young showed 3 distinct stages coinciding with the 3 stages of the nesting cycle. Prairie falcons were progressively less absent from the nesting territory during pre-incubation, almost continuously present during incubation, and increasingly absent during brood-rearing. Absence from the nesting territory differed among years and nesting stages, but not among study locations or nesting pairs. Percent absence of the day per pair during brood-rearing was similar between 1984 and 1987, but was higher in 1985 and highest in 1986.

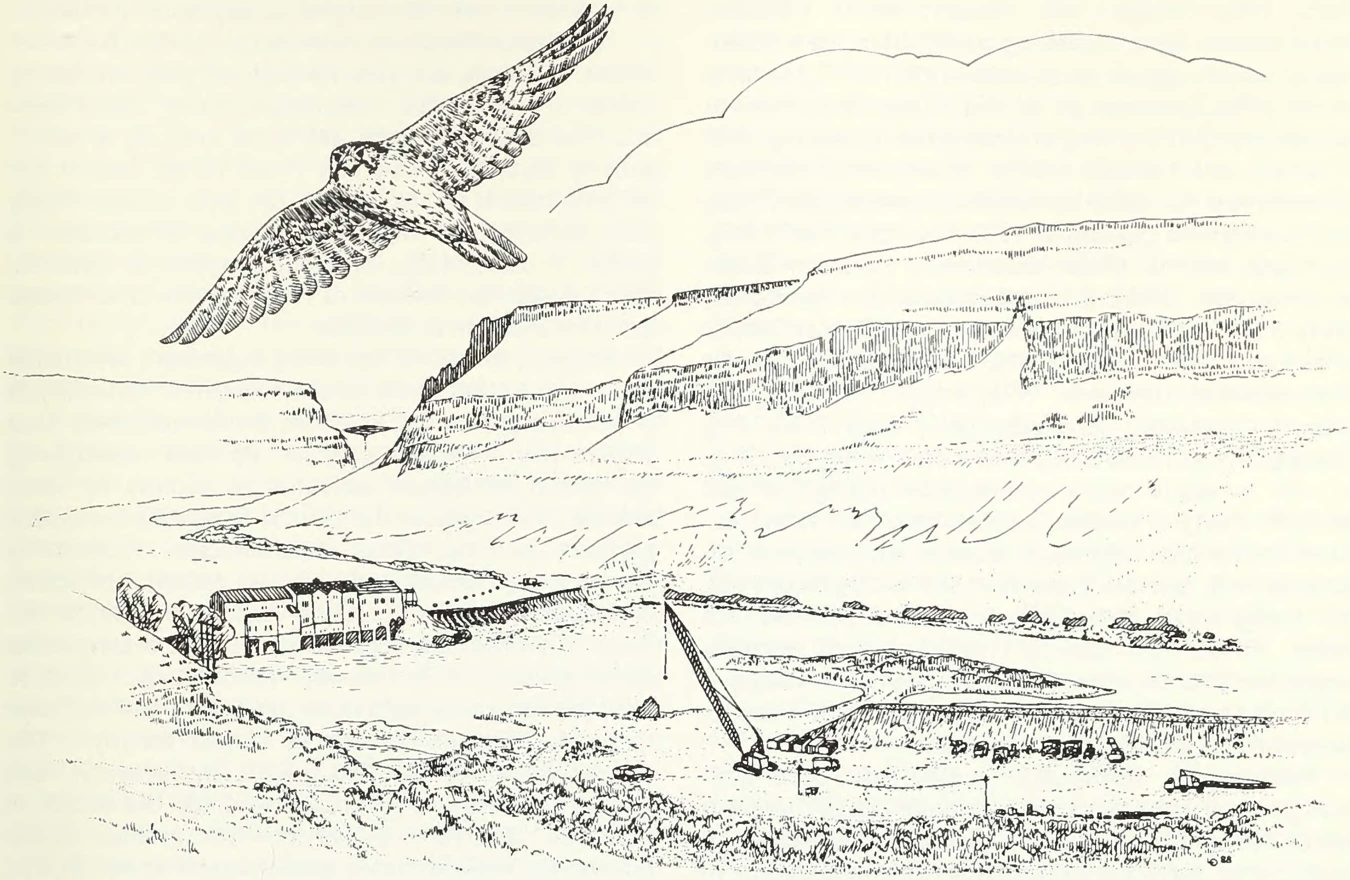
Occupancy of nesting territories in each of the 3 BOPA study locations in 1984-1987, was similar to 1976-1978, when complete surveys were carried out. Differences in productivity were not found among study locations for 1984-1987. Productivity of prairie falcons was not correlated with human activity in each nesting territory. Significant correlations were not found between mean weight of male and female nestlings and human activity. Nest failures occurred in all BOPA study locations. Three failures occurred in both the construction and control study locations, but 8 occurred in the recreation study location, of which 5 were in an area with high visitor use (Halverson Lake). The behavioral repertoire of falcon pairs whose nesting attempts failed was similar to that of successfully nesting pairs in the control study location.

Falcons, when present, reacted to blasting in 137 of 254 instances (54%). Incubating and brooding falcons were flushed in 25 of 112 instances (22%), but returned to their nests within 3.4 ± 0.7 (SE) min. Eggs were never dislodged when incubating falcons were flushed. The behavioral repertoire of falcons exposed to experimental blasting was similar to that of control pairs. All pairs exposed to experimental blasting and 2 of 4 pairs exposed to construction blasting fledged young. All nesting territories exposed to experimental blasting were occupied the year following blasting. In the second year following experimental blasting 3 of the 4 nesting territories were vacant. The vacancy rate did not significantly differ between nesting territories exposed to experimental blasting and those that were not.

Investigators did not affect the behaviors of falcons by approaching observation blinds placed 70-250 m from the aeries, or by different modes of access. No appreciable differences were found between observations collected from within or outside a blind. Observations collected from within or outside a blind were qualitatively and quantitatively similar in this study.

In general, this study demonstrated that construction and recreation activities had no detectable adverse effects on nesting prairie falcons. Some behaviors varied slightly whereas others exhibited considerable variation. The relatively stable behaviors appear to be particularly useful in evaluating human activities because small deviations could cause a nest failure.

Specific management recommendations based on this study are found under "Conclusions and Management Implications" and "Management Recommendations for the BOPA" in this report.



Preface

In 1972, the Bureau of Land Management (BLM) initiated a series of comprehensive ecological studies on all raptor species nesting along the Snake River canyon in southwestern Idaho to gather information for management of these raptor populations and habitats. The studies showed that the density of raptors nesting along the Snake River canyon was higher than in any other non-colonial area reported in the literature (U.S. Dep. Inter. 1979). In 1980 the Secretary of the Interior proposed congressional legislation that would establish the Snake River Birds of Prey National Conservation Area, totaling about 243,000 ha.

The Swan Falls hydroelectric dam is located in the section of the Snake River canyon with the highest density of nesting raptors. The Swan Falls hydroelectric power plant was built from 1899-1902 and was the first power plant on the Snake River. Following improvements in 1913, the power plant remained unchanged until the present. In 1984 the Idaho Power Company (IPC), joined in 1985 by the Pacific Gas and Electric Company (PG&E), engaged in a voluntary cooperative agreement with the BLM to investigate the effects of reconstruction activities at the Swan Falls hydroelectric power plant on nesting raptors. The results of this investigation are reported in the following pages.

Introduction

Human activities can affect both raptor behavior and breeding success. Raptors can be affected during the nesting cycle (Fyfe and Olendorff 1976), or outside the nesting season in areas important for feeding and roosting (Newton 1979). In general, it is thought that raptors are most sensitive to disturbance during courtship and egg-laying and less vulnerable towards the end of the incubation period or when they have young (Newton 1979). Human activities that may affect raptors include military exercises (Ellis 1981, Andersen et al. 1986); agriculture (Schmutz 1984); livestock grazing (Kochert et al. 1988); construction, mining, and blasting (Stahlecker and Alldredge 1976, U.S. Dep.

Inter. 1976, Haugh 1982, Bednarz 1984). Human activities may flush incubating adults from nests resulting in loss of eggs or small chicks (Platt 1977, Harmata et al. 1978, Roseneau et al. 1981), nest abandonment (Grier et al. 1977, 1978), or destruction of nesting cliffs (Postovit and Postovit 1987). Recreational activities have affected red-tailed hawks (*Buteo jamaicensis*) (Wiley 1973), accipiters (Hennessy 1978, Lee 1981, Hall 1984), European kestrels (*Falco tinnunculus*) (Van der Zande and Verstrael 1985), prairie falcons (*Falco mexicanus*) (Boyce 1977, 1988; Boyce and Garrett 1977), gyrfalcons (*Falco rusticolus*) (Platt 1977), bald eagles (*Haliaeetus leucocephalus*) (Steenhof 1978, Fraser 1984), ospreys (*Pandion haliaetus*) (Swenson 1979, Haga 1981, Van Daele and Van Daele 1982, Levenson and Koplin 1984), as well as entire raptor communities (Craighead and Mindell 1981). Studies on non-raptorial birds also demonstrate that increased human activities are associated with decreasing numbers of breeding birds (Van der Zande et al. 1980, 1984; Van der Zande and Vos 1984). Boyle and Samson (1985) reported generally negative effects of outdoor non-consumptive recreational activities on wildlife in studies they reviewed; few studies demonstrated positive or neutral effects.

Most raptor disturbance studies have been non-manipulative (i.e., the level of human activity was not controlled by the investigator). Manipulative disturbance experiments have been conducted with bald eagles to determine buffer zones around areas considered critical for feeding, nesting, or roosting (Stalmaster and Newman 1978, Knight and Knight 1984, Fraser et al. 1985). Investigators approached nesting and non-nesting bald eagles in a variety of ways and determined the distances at which the eagles would fly. Distances at which eagles took flight were highly variable depending on whether the birds were nesters or non-nesters, where they perched, or whether they were approached on foot, or by boat, car, or airplane. Failure rates of nesting ferruginous hawks (*Buteo regalis*) exposed to daily disturbances, which included approaches on foot or by vehicle, industrial noise, and shooting, were substantially higher than for undisturbed control pairs (White and Thurow 1985). The impact researchers may have on their study subjects has been investigated usually in a post facto examination of collected data (Fyfe and Olendorff 1976, Grier and Fyfe 1987, Am. Ornithol. Union 1988). Generally, effects of researchers on the breeding success of raptor species could not be detected (Grier 1969, Poole 1981, Grier and Fyfe 1987). Besides the above-mentioned studies, much of the currently available data on human disturbance of raptors are circumstantial, equivocal, or anecdotal (Suter and Joness 1981, Postovit and Postovit 1987). The paucity of factual data may lead to erroneous conclusions about the effects of human activities on raptors and may result in ineffective and costly raptor management guidelines.

Although information is available on the immediate effects of human activities on birds of prey, the lasting effects are uncertain. Sustained human disturbance activities in specific areas are likely to result in avoidance of such areas and may result in the loss of key habitats critical to activities of the birds (Fraser 1984). The sensitivity of raptors to human disturbance is subject to considerable intra- and interspecific variation, which makes the reaction of raptors exposed to human activities even more complex.

Raptors, like other free-living organisms, are limited by natural factors which induce substantial variability in population parameters and behavior of individuals from year to year. The challenge of any study investigating the effects of human activities on raptors or other wildlife is to separate the natural background variation ("noise") from the effects of disturbance. Productivity has been used almost exclusively to evaluate the effects of human activity on nesting raptors, but subtle behavioral changes that may have long-term consequences cannot be detected in this way. In this study, I chose to examine the entire behavioral repertoire and correlate this with variables measuring human activity. The reconstruction of the Swan Falls hydroelectric dam provided a unique opportunity to study the effects of industrial construction activities on nesting prairie falcons, the most common nesting raptor in the BOPA. Approximately 5-10% of all prairie falcons may nest in the BOPA (U.S. Dep. Inter. 1979). Prairie falcons inhabit the arid plains and steppes of interior North America, from central British Columbia and to Baja California. Their biology, ecology, and general habits are described by Skinner (1938), Enderson (1964), Brown and Amadon (1969), Evans (1982), and Becker and Ball (1983). Boyce (1988) documented a decline in prairie falcon productivity exposed to various human recreational activities in the Mojave desert. Prairie falcons have been reported to be sensitive to human disturbance and to abandon aeries when excessive human disturbance occurs (Call 1978). Becker and Ball (1983), however, made a milder assessment and stated that prairie falcons exhibit a moderate level of inherent sensitivity to human activities and might be a good indicator species. This study, which was initiated in 1984, had 2 specific objectives: to evaluate the effects of construction and recreational activities on the behavior and productivity of nesting prairie falcons, and to formulate management guidelines for industry and government agencies for nesting prairie falcons exposed to human activities.

Deviations from normal behavior patterns of falcons exposed to human activities would indicate possible effects of disturbance activities. Deviations in behavior may depress productivity (young fledged/pair), or influence the physical condition of the young, because attention could be directed away from eggs and young towards a perceived disturbance. The question remains what is "normal" behavior? Considerable inter-individual variation is the rule rather than the exception in the behavioral repertoire of most animals. For the purpose of this study I therefore defined normal behavior as the behavior patterns exhibited by falcons not, or minimally, exposed to human activities. Behaviors of falcons exposed to human activities that differ at the $P = 0.05$ level of significance from behaviors of falcons not, or minimally, exposed to human activities were considered possibly related to disturbance activities.

It may be useful to discuss the reaction of a falcon to human activities and its effects on the various behaviors in the context of the parental investment theory as proposed by Trivers (1972). The parental investment theory attempts to explain the interactions between a parent and its offspring, its mate, the environment, and predators in terms of allocating its resources to its young (Coleman 1987). Parental investment is defined as any investment by the parent in an individual offspring that increases the offspring's chance of surviving at the cost of the parent's ability to invest in other offspring (Trivers 1972). It follows that a decrease of the parental investment of a falcon in its offspring, as a result of human disturbance activities, will directly affect the falcon's reproductive success.

Raptors can react in 1 of 3 ways to human disturbance: 1) no behavioral response, 2) secretive behavior or avoiding the aerie to prevent detection of their reproductive effort, 3) perceiving the disturbance as a threat to their reproductive effort and showing a defensive behavioral response. The reaction to a disturbance activity may be related to the strength of the stimulus or its perception which may change over the course of the nesting cycle (Montgomerie and Weatherhead 1988). Many birds show a great tenacity to their reproductive effort and an increasing willingness to defend their eggs or young as the nesting season progresses (Fyfe and Olendorff 1976, Newton 1979, Montgomerie and Weatherhead 1988, Knight and Temple 1986a,b). Thus, the effect of the same stimulus may decline through the nesting cycle. Disturbances may occur at any time and therefore affect any behavior. Based on what is known about prairie falcons in general and the effect of disturbance activities on their behavior, I formulated the following predictions for each common prairie falcon behavior.

Copulations function to fertilize the eggs, but may also strengthen the pair bond and synchronize a pair's breeding behavior (Birkhead et al. 1987). Copulation frequency in prairie falcons has not been documented, and the number of copulations required to fertilize a clutch is unknown (Palmer 1988). Copulations are expected to peak during the female's fertile period (Birkhead et al. 1987) and subsequently decline to low levels, as was found in the peregrine falcon (*Falco peregrinus*) (Ratcliffe 1980). Apparently, prairie falcons are particularly sensitive to human activities during pre-incubation, and readily desert a nesting territory prior to egg-laying (Fyfe and Olendorff 1976). In this stage the pair is in the process of establishing a nesting territory and has not yet made an investment in their reproductive effort. I predict that copulation frequencies of falcons disturbed by human activities would be lower than those of falcons not exposed to such activities. This prediction may hold for the pre-incubation stage or over the entire nesting cycle. Lower copulation frequencies may result in a smaller number of fertile eggs and lower reproductive success.

In the incubation stage, the important variable is the total amount of time both parents spend incubating. Prairie falcons rarely abandon a nesting attempt once incubation has started (Fyfe and Olendorff 1976). Percent of time incubating in prairie falcons rapidly increases after the 1st egg has been laid and reaches a value of about 90% after 6 days (Enderson et al. 1973). From then on percent incubation per day may vary within narrow limits (Drent 1975). Disturbance activities may cause the falcon to temporarily vacate the aerie, leaving the eggs unattended. Thus, I predict that falcon pairs disturbed by human activities would spend less time incubating than pairs not exposed to such activities. Leaving eggs unattended for long periods of time may cause embryo mortality, lower hatching success, and depressed productivity (Drent 1975, Hunter et al. 1976).

Young of large falcons cannot regulate their body temperature until about 2 weeks after hatching and require brooding by a parent, usually the female (Enderson et al. 1973, Ratcliffe 1980, Poole and Boag 1988). The need for brooding may be decreased to some extent by a sheltered aerie and favorable weather conditions (Kaiser 1986). I predict that brooding falcons disturbed by human activities would spend less time brooding than undisturbed falcons. Unattended small young may chill or overheat (Fyfe and Olendorff 1976); both scenarios may increase the mortality rate of young and result in lower productivity.

Most prey delivered to the female or young is procured by the male prairie falcon (Palmer 1988). Prey delivered by the male falcon is particularly critical before laying, when the female is building up her body reserves to enable her to lay eggs, and during egg-laying, when the risk of damage to the eggs in the female's body is high and she is reluctant to leave the nesting territory (Newton 1979, 1986, 1988). When the young are small and have to be brooded most of the time, the male has to provide food for both the female and the young, as well as for himself. Raptors are known to cache prey items to dampen changes in food supply due to fluctuating prey availability (Collopy 1977, Rijnsdorp et al. 1981), or unfavorable hunting conditions (Nunn et al. 1976, Palmer 1988, Poole and Boag 1988), or to exploit a temporary abundance of food (Sitter 1983, Palmer 1988). This is of particular importance when the young are small and have to be fed at frequent and regular intervals (Ratcliffe 1980). Caching and retrieval rates of prey items are likely to be closely associated with the numbers of prey delivered to the nesting territory. Human activities may make falcons more reluctant to deliver prey items, thereby revealing the location of the aerie (Fyfe and Olendorff 1976). I predict that falcons disturbed by human activities may miss feedings, and show lower caching and retrieval rates. Lower prey delivery rates during pre-incubation may affect clutch size, may be insufficient for the female to produce eggs, or may even motivate her to abandon the nesting attempt altogether. During early brood-rearing, depressed prey delivery, caching, and retrieval rates may affect the physical condition of the young and the female. Over an extended period missed feedings are likely to increase the mortality rate of young, affect their physical condition, or result in a lower productivity.

I predict that falcons disturbed by human activities may be flushed more frequently and relocate more often than those falcons not exposed to such activities. The effects of higher relocation frequencies on reproductive success are unclear, but disturbance activities may put the falcon on the alert, resulting in reduced parental care and lower quality offspring.

Nesting raptors spend much time perched in their nesting territories (Newton 1979). Presumably, one of the functions of this behavior is to defend the nesting territory against potential predators and usurpers (Newton 1986, 1988). Falcons disturbed by human activities may avoid the nesting territory for fear of exposing the aerie. Thus, I predict that falcons disturbed by human activities would spend less time perching in their nesting territory than undisturbed falcons. However, the opposite may also hold true. When disturbance activities are perceived as a threat, the falcon may spend more time in the nesting territory to defend it. Regardless of the trend, changes in this behavior may affect parental care and lower reproduction.

Aggression functions to deter potential predators and usurpers (Olsen and Olsen 1980). The level of nest defense is likely to increase during the nesting cycle because offspring survival increases rapidly relative to that of the parents, i.e., the reproductive effort becomes relatively more valuable during the nesting cycle (Montgomerie and Weatherhead 1988). Such an increase has been found in peregrine falcons (Ratcliffe 1980). Prairie falcons patrol their nesting territory to establish boundaries (Ogden and Hornocker 1977, Sitter 1983). In the early pre-incubation stage patrolling may also function to advertise the nesting territory and attract a mate (Newton 1979). Once territorial boundaries are established, patrolling frequency is likely to decline during incubation and brood-rearing. I predict that falcons disturbed by human activities would show higher aggression and possibly patrolling levels than those falcons not exposed to such activities. An increase in nest defense behavior may reduce parental care and possibly lead to lower productivity. Disturbance may also result in unobtrusive behavior of the falcons and avoidance of the nesting territory. This may result in a decrease in nest defense and perhaps lower productivity.

I predict that human activities, particularly in areas where raptors have been persecuted, may induce nesting pairs to behave more secretively and leave the nesting territory until the perceived threat has disappeared. Such observations have been made with raptors (Fyfe and Olendorff 1976, Newton 1979), and non-raptorial birds (Knight 1984, Knight et al. 1987). Greater absence may result in reduced parental investment, possibly causing higher mortality rates and lower productivity. In the less likely event that falcons react with an increase in perching behavior and higher levels of nest defense, absence will decrease, but the overall effect will be the same.

Unfortunately, most predictions are necessarily vague, because a falcon pair can follow several strategies when reacting to human disturbance depending on inter-individual variation due to various biotic and abiotic variables. However, some behaviors are clearly more critical than others for a successful nesting attempt, and those deserve special attention. Downward trends in incubating and brooding behavior, prey delivery rates, and presence of falcons in nesting territories exposed to disturbance may represent responses to disturbance, as may changes in perching and aggressive behavior.

I predict that when disturbance activities take place during pre-incubation and incubation and cause desertion of the nesting territory, a lower occupancy rate can be expected in nesting territories exposed to disturbance activities than those that are not (Fyfe and Olendorff 1976). Falcons exposed to disturbance activities may also show lower productivity and have young of lower average weight than undisturbed pairs.

Study Area

The study area is part of the Western Intermountain Sagebrush Steppe (West 1983). Detailed descriptions of the climate, vegetation, and natural environment of the BOPA can be found elsewhere (U.S. Dep. Inter. 1979, West 1983). Nesting territories used for observations were subjected to 1 of 4 categories of human activities: industrial construction and recreation, recreation only, controlled blasting, and minimal human activities (control nesting territories). An aerie is defined as the physical location at which a falcon pair nests or attempts to nest. The nesting territory is a confined locality where aeries are found, usually in successive years, and where no more than 1 pair has ever bred at 1 time (Steenhof 1987). Nesting territories exposed to construction activities were located within 1 km of Swan Falls Dam (Fig. 1). Construction in the Swan Falls Dam area occurred from 1983 through 1986. In October 1983, an existing unpaved road leading down into the canyon was rebuilt below 3 traditional prairie falcon nesting territories at distances ranging from 60-300 m from the aeries. Heavy road construction (i.e., drilling and blasting) was carried out between October 1983 and late January 1984 (Appendix 1), before the prairie falcons returned to their nesting territories (U.S. Dep. Inter. 1979). However, the remaining road work (e.g., roadbed preparation, installation of guard rails, and paving) was not completed until May 1984, when the falcons were incubating or rearing their young. In May 1985, construction on Swan Falls Dam started after approximately 80% of the nesting season had passed. In 1986, heavy construction (including demolition of the old spillway and removal of the cofferdams and temporary bridges) continued throughout the nesting season. Construction was completed in the fall of 1986, and equipment was moved out by December. Lag effects of construction activities were evaluated in 1987.

Nesting territories located within 500 m of Dedication Overlook and in the Halverson Lake area were

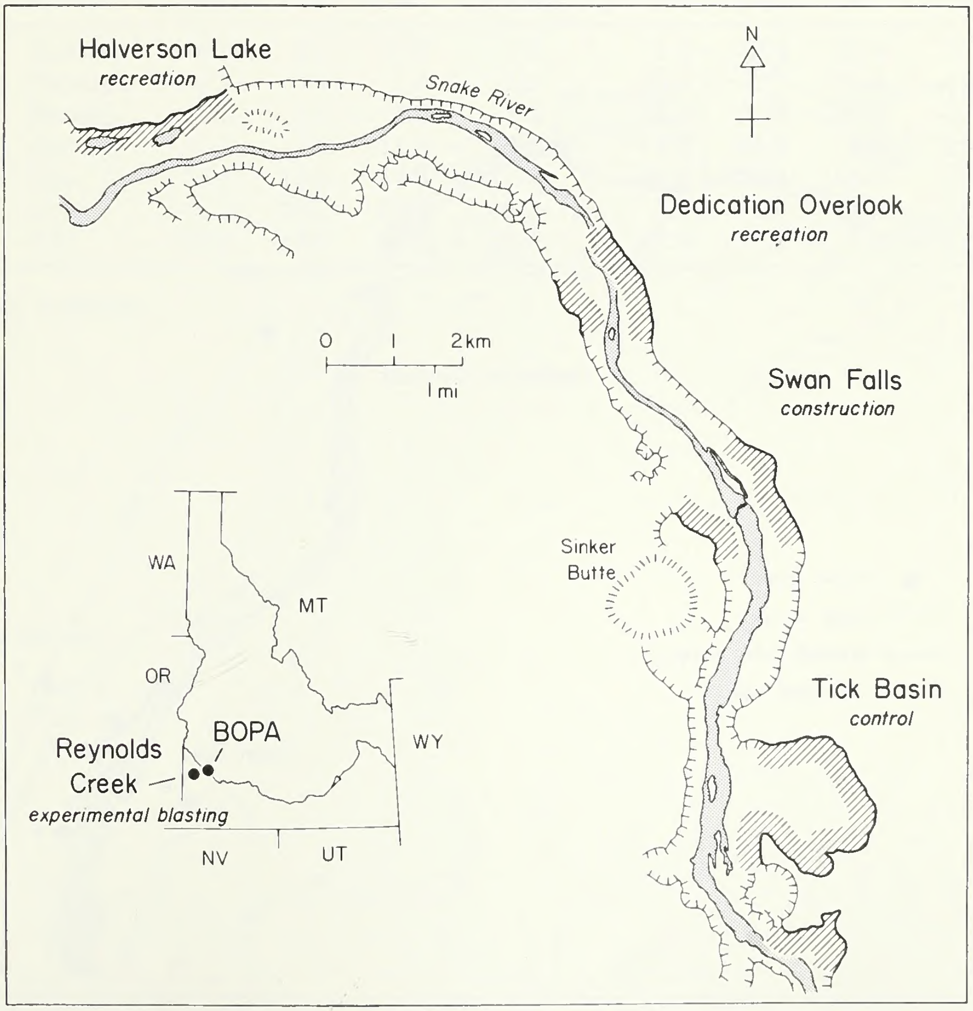


Fig. 1 Location of the study area.

used to evaluate recreational activities (Fig. 2). Recreation took place in the construction and recreation study locations, but was concentrated at specific sites with attractive features such as overlooks (Dedication Overlook and Three Poles Overlook, Fig. 2) and water for boating or fishing (along the Snake River and Halverson Lake, Fig. 2). Research in 1984 showed substantial recreational activities near Dedication Overlook which then served as the control study location. In 1985 a new control study location (Tick Basin) was selected. Tick Basin is located approximately 4 km upstream from Swan Falls Dam and receives little human use. A controlled blasting experiment conducted outside the BOPA was added in 1985 to separate the effects of blasting from other construction activities.

The blasting experiment was conducted in the foothills of the Owyhee Mountains (Reynolds Creek), outside the BOPA. Reynolds Creek is remote from major population centers and is difficult to access even by foot. Cattle ranching constitutes the major land use. The blasting study location is about 650 m higher in elevation than the BOPA. Annual precipitation at Reynolds Creek averages 280 mm (Hanson 1983), and the average annual temperature is 7.2 C. Detailed descriptions of the climate, vegetation, and geology of this area can be found in Hanson (1983) and Stephenson (1977).

The weather in 1984 was relatively cool and wet (Table 1). During the spring and early summer of 1985 the weather was warmer than usual and relatively dry. In Reynolds Creek average temperatures were about 5 C lower and precipitation was slightly higher than at Swan Falls. Late winter and early spring were wet in 1986, with precipitation 50% above average at Swan Falls. Early summer, however, was dry, with precipitation 75% below normal in June and July at Swan Falls and Reynolds Creek. In 1987 temperatures during late winter, spring, and summer were higher than normal. Late winter was dry; spring and early summer were relatively wet.

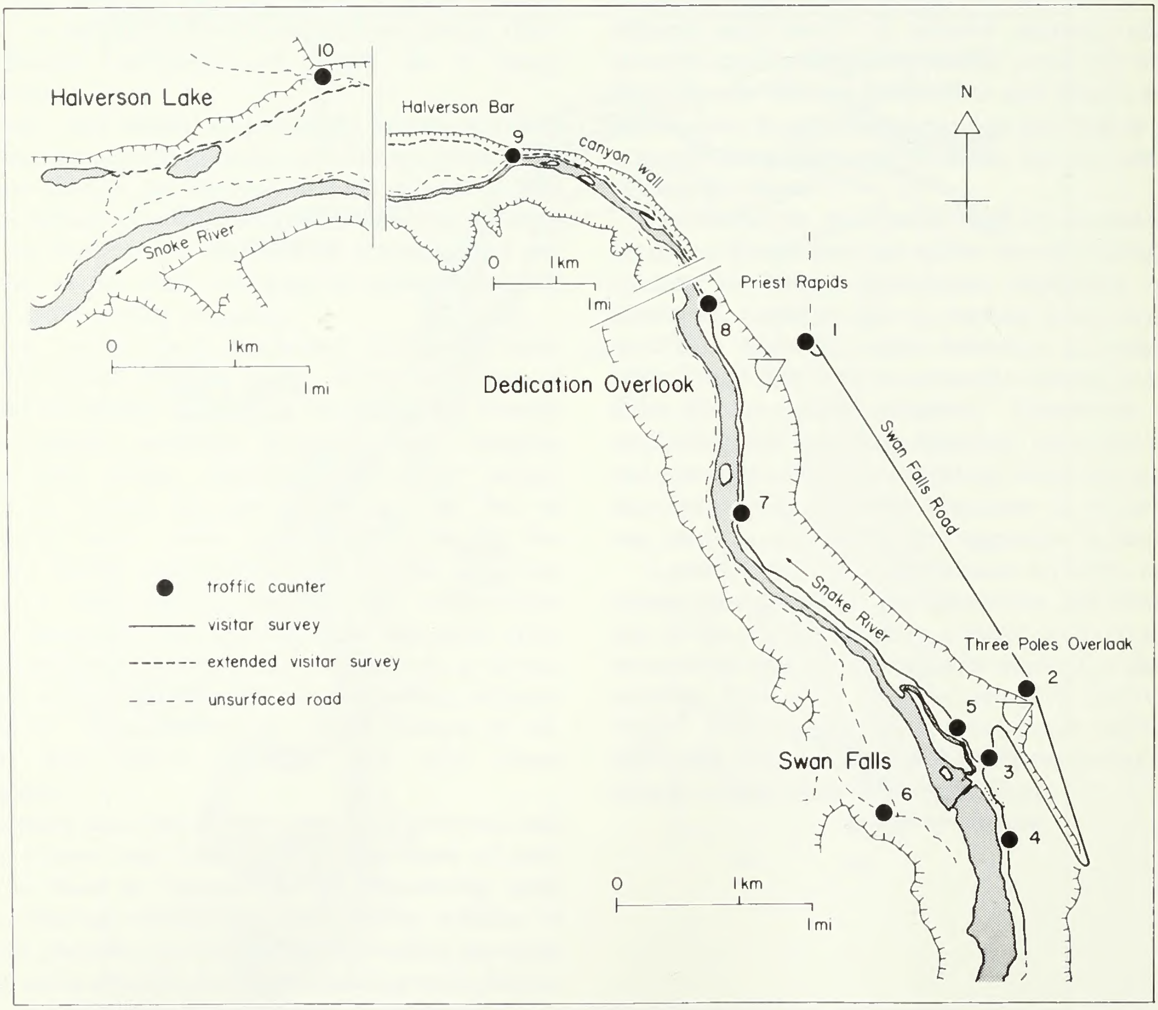


Fig. 2 Locations of traffic counters and the visitor survey route.

Table 1. Average monthly temperature (C) and total precipitation (mm) at Swan Falls Dam and Reynolds Creek, January-July 1984-1987, 1950-1980, and 1964-1981.

Swan Falls

	Temperature (C)					Precipitation (mm)				
Month	1984	1985	1986	1987	1950-80	1984	1985	1986	1987	1950-80
January	-2.9	-2.5	1.1	-0.6	0.7	9.0	6.5	16.8	10.6	22.3
February	1.1	-0.9	6.9	4.6	4.2	9.0	89.0	55.6	15.7	11.9
March	8.2	5.1	11.4	9.1	7.7	38.2	14.7	39.1	17.5	15.0
April	10.9	14.7	12.0	*	12.2	23.7	8.2	24.1	*	22.3
May	15.5	18.2	17.5	18.6	17.2	22.5	30.0	25.9	44.7	25.6
June	19.1	23.5	25.3	23.9	21.8	56.0	9.2	6.4	14.7	22.6
July	26.7	29.3	24.7	24.5	26.8	0.0	2.3	0.0	15.0	4.3

Reynolds Creek

	Temperature (C)				Precipitation (mm)			
Month	1985	1986	1987	1964-81	1985	1986	1987	1964-81
January	-5.3	0.7	-2.8	-1.5	2.0	17.3	19.3	36.0
February	-2.7	*	1.4	1.2	20.0	*	29.5	19.8
March	1.3	7.4	4.6	3.3	18.7	27.4	20.8	22.5
April	10.2	7.6	11.5	6.4	14.5	28.2	6.6	25.3
May	13.4	12.6	14.6	11.5	47.2	22.4	63.0	22.0
June	15.9	20.2	18.4	16.0	7.5	6.4	38.6	32.5
July	23.5	18.9	19.0	20.7	12.4	7.9	7.6	7.1

* No information available

Methods

Quantification of Human Activities

Two indexes of industrial and recreational activities were measured at or near each of the observed nesting territories: traffic flows and recreational activities. Traffic flows were measured with traffic counters (Autocount Cumulative Counter, Highway and Traffic Data Systems, Golden River Corp., Rockville, Md.) which were placed at (1) the Dedication Overlook parking lot (1985-87), (2) Three Poles Overlook (1985-87), (3) Swan Falls Road (1984-87), (4) 250 m upstream from Swan Falls Dam (1984-87), (5) 250 m downstream from Swan Falls Dam (1984-87), (6) the south side of the Snake River ("Murphy"; 1985 and 1987), (7) the property line between BLM and IPC land downstream from the dam (1985-87), (8) Priest Rapids (1985-87), (9) the south entrance to the Halverson Bar area (1987), and (10) the dirt road leading down into the canyon at Halverson Bar ("Halverson Trail"; 1987, Fig. 2). Data were collected daily, except at the 2 counters near Halverson Bar where the traffic counters were checked on weekends, and at Murphy which was checked every other day from March through late June. Traffic flows were calculated separately for weekdays and weekends because most recreational use of the Swan Falls area occurs on weekends (Holthuijzen 1985, 1986, 1987). Most traffic accessed the Swan Falls area along Swan Falls Road. A few vehicles, however, passed into the Swan Falls area from either the south side of the Snake River or along Halverson Trail, both of which require 4-wheel drive vehicles. Recreational traffic flows were recorded at counters located 250 m upstream and downstream from Swan Falls Dam. Recreational traffic flows were somewhat underestimated because some visitors parked at Swan Falls Dam without venturing farther upstream or downstream. Residential traffic flows were estimated on days when construction did not take place by subtracting recreational traffic flows from total traffic flows measured at Swan Falls Road. Residential traffic flows were fairly constant through the year (Holthuijzen et al. 1984). Construction traffic flows were estimated by subtracting recreational and residential traffic flows from traffic flows measured at Swan Falls Road. In analyzing the traffic flow data collected in 1985, 2 periods were distinguished: (a) prior to 13 May when construction did not take place, and (b) after 13 May when equipment was moved in and construction began.

Recreational activities (numbers of visitors, their locations, and activities) were estimated by daily visitor surveys of the construction and recreation study locations. From 1985 through 1987, 265 recreational surveys were conducted from late March through June along a predetermined route (Fig. 2). In 1987 on 1 day each weekend, usually Saturday, the recreational survey extended past Priest Rapids to Halverson Lake. Surveys started between 1400 and 1500 hours ($\bar{x}$ = 1424 ± 54 min, n = 259 surveys), when peak recreational use generally occurred. Surveys in the construction and recreation study locations took approximately 1 hour ($\bar{x}$ = 63 ± 23 min, range = 25-153 min, n = 234 surveys). When Halverson Lake was included, the surveys averaged 1.5 hours ($\bar{x}$ = 91 ± 49 min, range = 40-120 min, n = 15 surveys). Data on the location of visitors, their vehicles, and camp sites were plotted on 1:24,000 USGS topographic maps. Group sizes and activities of visitors were also recorded. Activities of visitors were subjectively weighted according to their potential to disrupt nesting raptors (Table 2). Number,

Table 2. Recreational activities recorded during visitor surveys in the BOPA, March-June 1985-1987 (*n* denotes numbers of visitors).

		1985		1986		1987		1985-87	
Activity	Weight*	%	*n*	%	*n*	%	*n*	%	*n*
Non-disturbing									
Fishing	1	42.9	1073	30.2	498	34.8	1028	36.6	2599
Moving vehicle	1	13.3	333	20.2	332	28.4	840	21.2	1505
Sightseeing	1	15.8	395	15.6	257	13.8	407	15.0	1059
Camping	1	5.2	131	6.1	101	7.7	228	6.5	460
Birdwatching	1	3.6	90	5.0	83	2.2	66	3.4	239
Boating (motor)	1	2.4	60	6.4	105	2.2	65	3.2	230
In parked vehicle	1	0.6	15	2.8	46	1.6	48	1.5	109
Boating (no motor)	1	1.3	32	1.1	18	1.7	49	1.4	99
Outfitter	1	2.6	65	2.0	32	0.2	5	1.4	102
Other	1	10.1	251	8.0	132	4.8	141	7.4	524
Subtotal		97.8	2445	97.4	1604	97.4	2877	97.6	6926
Disturbing									
ORV	2	1.1	28	2.1	35	2.0	60	1.7	123
Shooting	3	0.3	8	0.2	3	0.4	10	0.3	21
Rock throwing	2	0.3	8	0.2	3	0.1	3	0.2	14
Climbing cliff	2	0.3	7	0.0	0	0.0	0	0.1	7
Other disturbance	2	0.2	4	0.1	2	0.1	3	0.1	9
Subtotal		2.2	55	2.6	43	2.6	76	2.4	174
Total		100.0	2500	100.0	1647	100.0	2953	100.0	7100
No. surveys			89		76		100		265

* Weight assigned to recreational activity

sex, and age class (<19 years, 19-65 years, >65 years) of occupants of each encountered vehicle were recorded, as were the type of vehicle and license plate prefix. License plates provided information on the origin of the visitors. Based on the number, locations, and activities of visitors, a visitor use index was calculated for each day for the construction and recreation study locations. Visitor numbers from March through June were estimated by multiplying the daily number of vehicles entering the canyon along the Swan Falls access road by the average number of occupants per vehicle.

Quantification of Prairie Falcon Behaviors

Training of Field Personnel

Field personnel observed prairie falcons for at least 2 weeks in the field prior to regular behavioral observations. This provided sufficient time to determine aerie location, become familiar with prairie falcon behavior, make accurate and consistent observations on falcon behavior, and take standardized field notes. To improve and accelerate note-taking techniques and to familiarize field personnel with common falcon behaviors, indoor training was provided in the monitor room of The Peregrine Fund, Inc.'s World Center for Birds of Prey in 1986 and 1987. All assistants spent 1 morning observing mated peregrine falcon pairs on monitors and recording their behaviors in standardized form. I evaluated the notes and suggested improvements. In addition, each assistant received written instructions on note-taking protocol prior to the commencement of the field work. Early in the field season, I spent up to one full observation period in a blind with each field assistant to further standardize observation techniques and maximize data consistency.

Field Methods

During the 2nd and 3rd weeks of March, occupied prairie falcon nesting territories were located in the BOPA study locations. Each year from 1984-1987, 4 nesting territories were used for behavioral observations in the construction study location, and 4-6 were used in the recreation study location. Each year from 1985-1987, 4-5 nesting territories were used in the control study location. In 1985, 4 nesting territories were observed in the blasting study location. Behavioral observations were made from blinds below the aeries at distances that were considered optimal for viewing. The average distance from a blind to an aerie was 147 m (range = 70-250 m) (Table 3). At Halverson Bar, blinds were not used because they would have attracted recreationists, thereby interfering with the observations. Blinds were accessed by foot along the same route. None of the access trails took the observer closer to the aerie than the distance at which the blind was placed.

Separate records were collected for the male and female falcon forming a pair (focal animal sampling, Altmann 1974). Sex was determined by sex-specific behavior, such as position of the falcons during copulations and food begging by the female. Female prairie falcons also are considerably larger than males (Palmer 1988). A stylized drawing of the facial pattern of each bird further assisted identification of falcons forming a pair. In this study continuous sampling was used; instantaneous sampling tends to bias towards behaviors that occur at low frequencies (Tacha et al. 1985). I recorded the time (min) spent on pre-determined activities by each falcon (Table 4, Appendix 2). The frequency and duration of these behaviors during an observation day were later calculated separately for each sex. Interactions between the focal pair, conspecifics, and other birds or mammals were classified as aggressive, non-aggressive, or defensive (Appendix 2). Data on behaviors of nestlings were not collected.

An entire day was chosen as the sampling unit to avoid sampling problems related to daily behavioral cycles of the falcons (Altmann 1974, Fraser 1984). Observations started 30 min before sunrise and were terminated 30 min after sunset. Control nesting territories were observed once every 6 days. In the recreation study location, more observations were scheduled on Saturdays when visitor use was high. In the construction study location, sampling days were scheduled on weekdays when construction took place. When potentially disruptive activities (e.g., blasting) were planned, nesting territories closest to the disturbance were observed. However, a sampling schedule of 1 observation day each 6 days was adhered to as closely as possible. Overall, each nesting pair was observed for an average of 12 ± 3 days (range = 5-18 days, *n* = 52 nesting pairs). Observations were carried out by 2 observers, each on a half-day shift. Field assistants were systematically rotated through all observed aeries and alternately observed mornings and afternoons to minimize observer bias. A 10-45x spotting scope and 7x35 or 10x50 binoculars were used to make observations. Observations in the BOPA started during the last week of March each year; observations in Reynolds Creek started during mid-April of 1985. Observations continued until the young were 30-35 days of age (early June to mid-July) or the nesting attempt failed, which sometimes took several additional observation days to confirm.

Table 3. Distances (m) from blinds to prairie falcon aeries.

Aerie	Distance (m) 1984	1985	1986	1987
Construction study location				
Swan Dam Three Poles	200	170	-	119
Swan Dam Road Turn	-	-	137	-
Swan Road N Side	225	190	190	82
Ferry	140	146	-	-
Falcon Flats Fingers	250	177	159	151
Falcon Flats Black Rock	-	-	164	-
Swan Dam Road South Side	-	-	-	87
Recreation study location				
Priest Rapids I	250	230	-	-
Camera	-	137	114	91
PF I	155	-	-	-
PF II	190	173	118	105
Dedication Site	-	-	105	101
Halverson Upper Lake	-	-	105	-
Halverson Dunes	-	-	-	110
Halverson Trail	-	-	-	119
Priest Upper	170	160	123	110
Control study location				
Tick City	-	125	-	101
Tick I	-	-	95	-
Tick II	-	182	182	96
Tick III	-	105	105	105
Red Trail	-	135	-	128
San Sebastian Basin	-	-	114	119
Blasting study location				
Reynolds Lower	-	70	-	-
Reynolds Midcanyon Point	-	105	-	-
Reynolds Upper Road	-	150	-	-
Reynolds Midcanyon Cup	-	137	-	-
Mean	198	150	132	108

Observation days were categorized in 6-day intervals based on the approximate day of the nesting cycle relative to the female's estimated clutch completion date (day 0) and labelled by midpoints (pre-incubation, *n* = 91 days: days -51, -45, -39, -33, -27, -21, -15, -9, and -3; incubation, *n* = 267 days: days 3, 9, 15, 21, 27, and 33; and brood-rearing, *n* = 255 days: days 34, 39, 45, 51, 57, 63, and 69). Day 34 was included when falcons had newly hatched young, but would otherwise have been classified as incubating or brood-rearing with young 3-7 days old. At the time of hatching the behavior of the adults is distinctly different from either incubating falcons or falcons that had young 3-7 days of age (Holthuijzen pers. obs.). Hatching dates were estimated by back-dating estimated ages of young, which were in turn determined with a photographic aging key (Moritsch 1983). Start of incubation was calculated based on a 34-day incubation period (Burnham 1983), although incubation periods of 35 to 36 days have also been reported (Schwartz et al. 1977). Observations averaged 1.8 ± 1.9 days (range = 0-9.0 days, *n* = 52 nesting pairs) per aerie during pre-incubation, 5.1 ± 1.4 days (range = 1-8.0 days, *n* = 52) during incubation, 4.9 ± 2.4 days (range = 0-9.0 days, *n* = 52) during brood-rearing, and 0.3 ± 1.1 days (range = 0-7.0 days) during post-failure. Each aerie was observed for an average of 180 ± 39 hours (range = 84-272 hours, *n* = 52), totaling 9,380 hours for all aeries and years combined (Table 5).

Table 4. Behavior categories used in continuous observations of prairie falcons.

Duration	Frequency
perching	patrol
preening	aggressive encounter
incubating	copulation
brooding	relocation
nest visit	prey delivered
out-of-view	prey cached
out-of-canyon	prey retrieved
in scrape out-of-view	feeding adult
perched out-of-view	feeding young
flight-in-canyon	

Quantification of Blasting Activities

Controlled blasting began as soon as the aeries in Reynolds Creek were located. Two pairs were in their 2nd day of incubation, and the other 2 pairs were in their 6th and 14th day of incubation. Kinestik (Kinepak Inc., Lewisville, Tex.) charges (167 g of ammonium nitrate) were detonated on a rock surface facing the aerie at an average distance of 127 m (range = 120-140 m). Each aerie was exposed to a sequence of 3 blasts a day at 3-hour intervals. The sequence was repeated every other day and continued until the chicks were 35 days old. Each aerie was exposed to an average of 90 ± 2 blasts over a period of 62 days (Table 6). A Bruel and Kjaer 2230 Precision Sound Level Meter (Bruel and Kjaer Instruments, Inc., Marlborough, Mass.), with maximum peak hold capability and a 20-dB microphone input attenuator (150 dB maximum input) were used to measure noise levels. A Nagra IV-SJ tape recorder (Nagra Magnetic Recording, Inc., Hollywood,

Table 5. Observation effort at the 4 study locations, 1984-1987.

	1984			1985			1986			1987			1984-1987		
Study Location	Aeries	Days	Hours	Aeries	Days	Hours	Aeries	Days	Hours	Aeries	Days	Hours	Aeries	Days	Hours
Construction	4	49	712	4	50	737	4	52	782	4	51	758	16	202	2989
Recreation	4	40	581	4	56	831	5	61	914	6	65	971	19	222	3297
Control	-	-	-	4	56	831	4	55	819	5	52	756	13	163	2406
Blasting	-	-	-	4	45	688	-	-	-	-	-	-	4	45	688
Total	8	89	1293	16	207	3087	13	168	2515	15	168	2485	52	632	9380

Table 6. Average time of detonation (hours and min) at each nesting territory in the blasting study location, 1985.

	Time of Controlled Blasting (hours)			
Charge	Reynolds Lower	Reynolds Midcanyon Pt	Reynolds Upper Road	Reynolds Midcanyon Cup
One	0846 ± 33	0720 ± 40	0856 ± 54	0759 ± 30
Two	1149 ± 38	1022 ± 43	1157 ± 57	1101 ± 36
Three	1453 ± 41	1320 ± 40	1455 ± 61	1406 ± 38
Total charges	90	91	87	92
Blasting Days	30	31	29	31

Calif.) was attached to the meter to record sound data for laboratory analyses. Sound level data were collected in 3 separate experiments to determine impulse noise levels for Kinestik and dynamite detonations, noise levels at aeries exposed to blasting in 1985, and noise level propagation (i.e, noise level attenuation with increasing distance from the detonation site). Noise level tests were conducted on 27-28 August 1986. The weather was sunny and clear with 0-10 km/hour winds. Because dynamite is widely used as a blasting agent, we compared peak noise levels of 5 charges of dynamite (500 g) and Kinestik. The charges were detonated on the ground 100 m from the measuring equipment. Peak noise levels averaged 145 dB (range = 144-146 dB) for dynamite and 140 dB (range = 138-141 dB) for Kinestik (mixed 1 hour prior to detonation). Peak noise levels produced by Kinestik charges at the entrances to 2 aeries of nesting territories exposed to blasting in 1985 averaged 136 dB (range = 129-141 dB) and 139 dB (range = 139-140 dB). The differences were probably caused by the terrain and charge placement. Kinestik charges were set off in a dry wash on flat sandy ground at 100, 200, and 400 m from the measuring equipment to determine noise level propagation. Peak noise levels decreased about 8 dB with a doubling of the distance from the blasting site, which conforms to the noise level attenuation predicted for a source close to the ground.

From 7 April through 13 May 1986, construction crews detonated 24 charges at Swan Falls Dam, with an average charge of 39 ± 37 kg dynamite (range = 1.5-111 kg). Usually, only 1 blast took place per day (1630 h), but occasionally 2 charges were detonated (at 1200 h and 1630 h, respectively). All charges were detonated underground or in concrete structures. Aeries in the Swan Falls study location were an average 810 ± 205 m (*n* = 4) (range = 560-1000 m) from the blasting site. Two pairs were incubating when blasting started (1st and 4th day of incubation), and 2 other pairs completed their clutches during blasting (estimated clutch completion dates, 12 and 16 May). Peak noise levels were not measured during construction blasting.

Behaviors of falcons (e.g., perching, incubating, brooding) were recorded continuously from a maximum of 30 min prior to a scheduled blast to a maximum of 30 min after a blast. I used "readjustment" time to quantify the instantaneous behavioral reaction of falcons to a blast. Readjustment time was defined as the time elapsed before the falcons resumed the behavior they were engaged in immediately prior to the blast (e.g., perching, incubating, brooding). Of the 806 observations made during blasting, 48 were made during pre-incubation, 342 during incubation, and 416 during brood-rearing. In 552 instances (72.5% and 53.1% in the experimental and construction study locations, respectively), falcons were absent from the aerie or their presence could not be ascertained. Therefore, only 254 blasting instances were used in analyses.

Ranking of Aeries Exposed to Human Activities

Seven human activity indexes were used to rank the aeries observed from 1984 through 1987: (1) the average number of visitors observed per day from blinds weighted by their activity, (2) the average number of heavy or noisy vehicles and machinery (i.e., trucks over 2 tons, construction equipment, noisy machinery) recorded per day from blinds (3) the average traffic flows per day recorded at a traffic counter nearest to the ranked aerie, (4) the total number of explosions which took place in the construction and blasting study locations, (5) the average number of people weighted by their activity recorded during a visitor survey on a weekend day, (6) the distance from the aerie to the nearest road, and (7) the distance from the blind to the aerie. Based on a strong linear relationship between traffic flows and numbers of visitors (weighted by their activities) from 1985 through 1987, the daily number of weekend visitors in 1984 was estimated using the 1984 traffic flow data. All aeries observed from 1984-1987 were ranked in relation to each other according to each of the 7 indexes, and the ranking scores were summed per aerie. Thus, each observed aerie (*n* = 54 aeries) was ranked. These composite scores were used in correlation analyses with falcon behaviors.

Quantification of Observer Impact

The potential effect of an observer on the behavior of prairie falcons under observation was evaluated by comparing behavior of the falcons before, during, and after an observer approached or left a blind, generally during the midday shift. In the morning observers arrived at the blinds before sunrise; and in the evening they left after sunset, when the falcons were generally roosting. I considered a change in behavior of the falcons during the time an observer was approaching or leaving a blind a reaction to the observer. The data were collected from early May 1985 through the remainder of that nesting season and throughout 1986 and 1987. Blinds were always approached along the same access routes. In 1986 and 1987 blinds were approached on foot for the last 400 m. Vehicles were not used within a 400-m radius around the blinds in 1986 or 1987.

In 1986 and 1987, 1 nesting territory (Priest Upper) was used to study the effects of collecting data from within or outside a blind on the falcons' behavior. Observations were made once every 6 days by the same pair of observers alternately sitting inside or outside the blind during morning or afternoon shifts on subsequent observation days. This enabled me to compare behaviors of the falcons among mornings and among afternoons of the same nesting stage.

Occupancy and Productivity

Productivity (young fledged per pair) was determined by counting the number of young per occupied territory that reached 30 days of age (sensu Steenhof 1987). Age of young was estimated using a photographic aging guide (Moritsch 1983). Regular ground surveys were conducted from late May through June to determine occupancy and productivity of nesting territories within the study locations that were not observed from blinds. In 1987 productivity surveys in the BOPA were also conducted in the Falcon Flats and Balls Basin areas, and the area between Balls Basin Point and Wildhorse Butte (Kochert et al. 1986, Fig. 2). These areas were surveyed between late March and mid-April and thereafter at approximate 3-4 week intervals until early June. In 1985-1987, surveys in Reynolds Creek started during the last week of March. Two to 5 weeks were spent determining occupancy of nesting territories and locating the aeries. Productivity was determined by re-visiting all nesting territories at 2-3 week intervals starting in mid-May.

Weights of Young

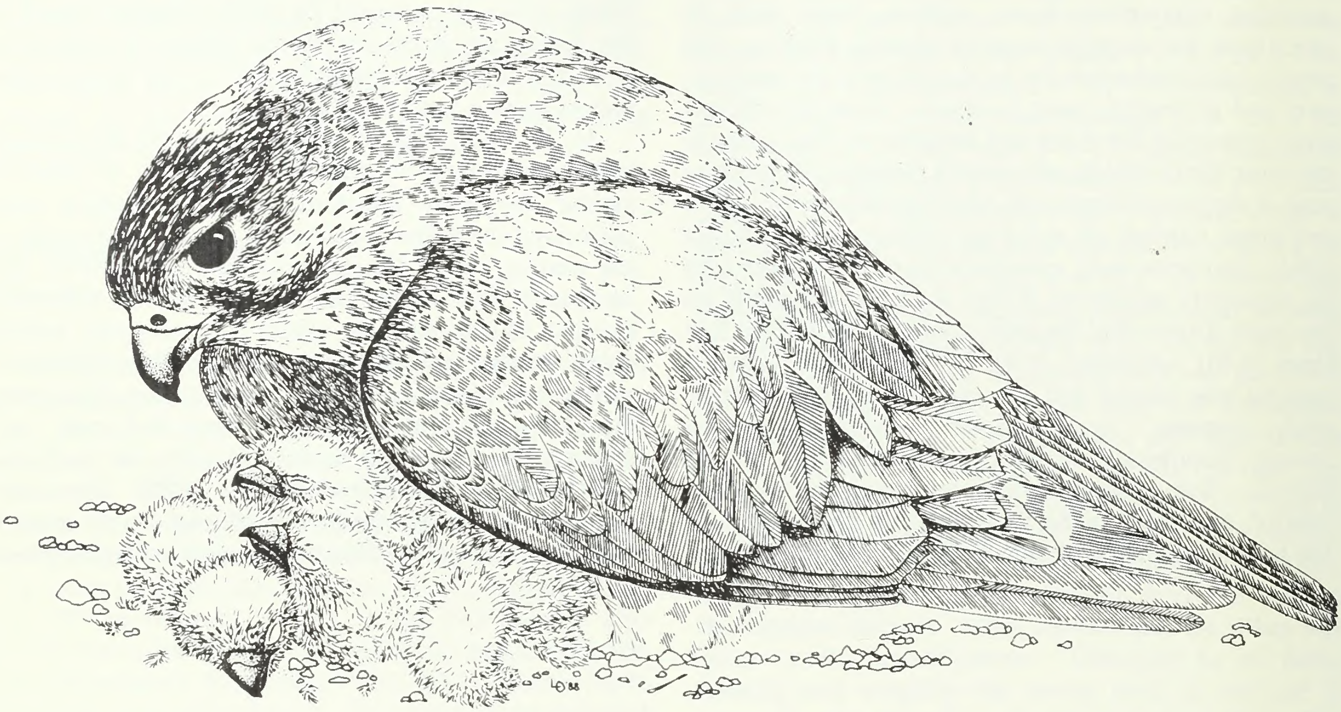
In 1986 and 1987 I attempted to band and weigh young at all identified aeries in the BOPA and Reynolds Creek study locations when they reached an estimated age of 30 days. Weight of young was recorded using a 1000 g Pesola spring balance. Crop fullness was estimated in increments of 25%. Weight was adjusted for crop fullness, i.e., a full crop was assumed to weigh 28 g for falcons < 550 g; 44 g for individuals 551-770 g; and 60 g for birds > 700 g (U.S. Bur. of Land Manage. unpubl. data). Morphological measurements taken were wing chord (wing straightened but not excessively flattened); tarsus length and width (at the narrowest point); culmen width, depth, and length; and footpad length (tip of the middle toe to the tip of the hallux with the foot fully extended). Prairie falcon young reach their asymptotic weight when they are about 25 days old (Fowler 1931, Sitter 1983) and show a pronounced size dimorphism between the sexes. Young banded with U.S. Fish and Wildlife band size no. 7 were considered females and those banded with no. 6 band size males (see Young and Kochert 1987). Young considered males had small tarsi widths (lateral $\bar{x} = 6.3 \pm 0.3$ mm, range = 5.5-7.2 mm; dorsal $\bar{x} = 7.2 \pm 0.5$ mm, range = 5.3-8.3 mm, $n = 82$) and small footpads ($\bar{x} = 75.8 \pm 3.2$ mm, range = 57.2-81.6 mm, $n = 82$); young considered females had large tarsi widths (lateral $\bar{x} = 7.8 \pm 0.5$ mm, range = 6.8-9.5 mm; dorsal $\bar{x} = 8.7 \pm 0.6$ mm, range = 6.9-10.5 mm, $n = 66$) and large footpads ($\bar{x} = 88.0 \pm 5.4$ mm, range = 68.4-97.4 mm, $n = 66$). In 1986 young were banded with red laminated plastic bands showing 2 unique white numbers (Ward 1975) on the left leg. In 1987 a blue anodized aluminum band was used with 2 unique white numbers (Acraft Sign and Nameplate Co., Edmonton, Alta.). Young were also banded with a U.S. Fish and Wildlife Service band on the right leg. In total, 151 young were weighed (37 and 114 young in 1986 and 1987, respectively), of which 149 were banded. One young died during banding, apparently from stress. Weights of 2 young banded in 1986 were not used in the analyses because 1 had starved and the other was taken in for rehabilitation. Climbing to an aerie, banding and weighing the young took an average of 132 ± 52 min (range = 30-270 min, $n = 46$). The young were taken out of the aerie, hooded, and placed in tight-fitting cardboard tubes to avoid damage to body and emerging feathers and to provide additional protection during handling. After the measurements were taken, the young were fed beef heart moistened with water. Banding took place in the morning (0600-1100 h) and late afternoon or early evening (1800-2100 h) to avoid heat stress.

Data Analysis

The frequency and duration of a pre-defined behavior was calculated for each nesting territory, observation day, and sex. An observation day for 1 of the falcons forming a pair constituted the sample unit for all analyses. Because day length increased from approximately 12 to 16 hours during the field season, direct comparisons of behaviors expressed in absolute time (min) could not be made. Therefore, the percentage of daylight hours spent on each behavior was calculated. Percentage data were arcsine-square root transformed to stabilize the variance and to conform the data to the normality assumption that is required for parametric statistical tests (Sokal and Rohlf 1981). Frequency data were used for behaviors of short (< 1 min) duration (e.g., copulations). Data expressed as percentages were used for behaviors of longer duration (e.g., incubating; Table 4). Frequency data were analyzed both per hour and per day.

Two approaches were used to test the possible effects of human activities on prairie falcon behavior. First, principal component factor analyses were used to investigate associations between human activities and prairie falcon behaviors for pairs nesting in the construction and recreation study locations. Separate analyses were performed for males and females. In each analysis, the basic factor matrix was rotated (varimax rotation) to seek a simple structure and describe each factor with a minimum number of variables (Dillon and Goldstein 1984). Variables were considered to be either positively or negatively associated if they loaded significantly on the same factor (i.e., loadings greater than 0.50 or less than -0.50) (Rummel 1970, Manley 1986). Factor analysis was carried out for exploratory, not confirmatory, reasons: to investigate possible associations among disturbance variables and behaviors of the falcons. Two human activity variables, "people" and "traffic", were used in the factor analyses performed with the behavioral data collected from 1985-1987. The total number of visitors observed during the recreation survey, weighted by their activities (Table 2) on a particular observation day, was used to estimate "people" in the construction and recreation study locations. Traffic flows as measured by traffic counters placed at the Swan Falls Road and in the recreation study location constituted the index "traffic" in the construction and recreation study locations.

In the 2nd series of analyses, stepwise discriminant analysis was used to test for differences in behavior among the study locations. Separate analyses were performed for males and females in each of 3 stages of the nesting cycle. Falcon behaviors, productivity, and occupancy data were also analyzed using univariate statistics to determine the effects of nesting year, nesting stage, nesting territory, and study location. Nonparametric tests were used when assumptions concerning normality and homoscedasticity were not met. All statistical analyses were carried out using the Statistical Analysis System (SAS Institute, Inc. 1985). Tests were evaluated at the 0.05 level of significance. Variation is expressed as standard deviations, unless otherwise noted.



Results

Human Activity

Traffic Flows

Weekday traffic flows along the Swan Falls access road steadily increased from 1984 through 1986 when construction was in progress, then declined in 1987 although still at almost twice the 1984 level (Table 7 A). Weekday traffic flows at Dedication Overlook were similar in 1985 and 1987 (13.1 and 11.8 vehicles/day, respectively), but averaged only 3.1 vehicles/day in 1986 when the parking lot was under construction. Traffic flows at Three Poles Overlook were highest in 1985 (16.0 vehicles/day) but showed a sharp decrease in 1986 (6.9 vehicles/day) and remained at this level in 1987 (7.0 vehicles/day). Upstream traffic flows were about 3-6 times higher in 1987 (30.2 vehicles/day) than in previous years. Downstream traffic flows were 1.2-2 times higher in 1987 (32.3 vehicles/day) than in previous years. Traffic flows decreased at the BLM/IPC traffic counter (no. 7, Fig. 2) from 1985 through 1987 (10.6, 8.0, and 5.7 vehicles/day in 1985, 1986, and 1987, respectively), but remained at about the same level at Priest Rapids (6.0, 6.3, and 7.5 vehicles/day in 1985, 1986 and 1987, respectively). Traffic entering the Snake River canyon from the south side remained at about the same level in 1985 and 1987 (2.4 and 3.1 vehicles/day, respectively).

Weekend traffic flows showed similar trends (Table 7 B). At Swan Falls Road, high traffic volumes were recorded in 1985, with a decrease in subsequent years (327.7, 263.8, and 224.4 vehicles/day in 1985, 1986, and 1987, respectively). However, traffic flows in 1987 did not decline to pre-construction levels (169.1 vehicles/day in 1984). This trend was also observed for traffic flows at Dedication Overlook and flows directed either upstream or downstream from Swan Falls Dam. Traffic flows recorded at the BLM/IPC counter decreased from 1985 through 1987 (43.6, 30.8, and 20.4 vehicles/day, respectively). At Priest Rapids, however, traffic flows were higher in 1987 than in preceding years. Of all vehicles accessing the canyon along the Swan Falls access road on weekends, 52.3% continued either upstream or downstream. Only 28.3% of all vehicles

Table 7. Traffic flows (vehicles/day) in the BOPA on (A) weekdays and (B) weekends, 25 March-25 June 1984-1987 (*n* denotes numbers of days).

A. Weekdays

	1984			1985			1986			1987		
Location	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
Swan Falls Road	68.1 d*	28.2	50	178.6 b	103.7	66	211.0 a	75.9	61	102.9 c	41.3	63
Dedication Overlook	-	-	-	13.1 a	12.2	66	3.1 b	2.2	66	11.8 a	8.8	65
Three Poles Overlook	-	-	-	16.0 a	12.1	66	6.9 b	7.1	66	7.0 b	4.5	65
Upstream	11.4 b	8.3	53	8.8 b,c	6.9	66	4.5 c	4.7	64	30.2 a	21.8	54
Downstream	14.4 c	8.0	56	25.4 b	20.9	66	13.3 c	7.7	64	32.3 a	17.2	63
IPC/BLM	-	-	-	10.6 a	8.9	66	8.0 a,b	8.2	60	5.7 b	4.4	63
Priest Rapids	-	-	-	6.0 a	5.2	66	6.3 a	5.8	66	7.5 a	6.1	63
Halverson Gate	-	-	-	-	-	-	-	-	-	17.3	10.5	9
Halverson Trail	-	-	-	-	-	-	-	-	-	13.3	7.8	8
Murphy	-	-	-	2.4 a	1.8	47	-	-	-	3.1 a	2.9	23
Residential	42.2 c	27.7	48	63.9 b	29.3	66	74.7 a	-	-	38.7 c	40.6	50
Construction	0.0	-	-	139.8 a	91.8	38	118.8 a	74.4	57	0.0	-	-

B. Weekend-days

	1984			1985			1986			1987		
Location	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
Swan Falls Road	169.1 c	62.1	21	327.7 a	118.2	26	263.8 b	122.1	25	224.4 b,c	111.9	26
Dedication Overlook	-	-	-	29.6 a	18.2	26	8.6 b	5.2	27	34.4 a	13.1	26
Three Poles Overlook	-	-	-	51.4 a	20.1	26	18.9 b	7.8	27	19.0 b	10.4	26
Upstream	42.5 b	24.3	22	29.7 b,c	14.6	26	15.7 c	10.7	26	75.2 a	47.5	24
Downstream	47.5 c	26.2	24	79.6 b	58.9	26	39.4 c	18.4	27	103.5 a	41.5	22
IPC/BLM	-	-	-	43.6 a	20.5	26	30.8 b	18.9	25	20.4 c	12.7	24
Priest Rapids	-	-	-	18.9 b	14.1	26	18.7 b	9.6	27	28.4 a	17.0	24
Halverson Gate	-	-	-	-	-	-	-	-	-	42.0	30.6	21
Halverson Trail	-	-	-	-	-	-	-	-	-	26.2	16.2	20
Murphy	-	-	-	4.8 a	3.3	20	-	-	-	3.3 a	4.0	16
Residential	67.3 a,b	29.9	19	99.7 a	97.9	26	74.7 a,b	-	-	53.1 b	87.0	20
Construction	0.0	-	-	48.9	82.8	21	-	-	-	0.0	-	-

* Means followed by the same letter(s) do not differ significantly among years at $P = 0.05$, based on Duncan's multiple range test.

entering the canyon passed into public land downstream of the dam and 8.5% passed Priest Rapids. Vehicles that accessed the canyon along Halverson Trail in 1987 frequently continued upstream past Halverson Gate. Traffic also accessed the canyon along a trail on the south side of the canyon but at low numbers (4.8 and 3.3 vehicles/day in 1985 and 1987, respectively). Vehicles entering the Snake River canyon by the Swan Falls road or Halverson Trail were likely to stay within 6 km of the access points. Traffic flows generally increased from early spring (March-April) until early summer (May) and slowly declined after Memorial Day when hot summer weather set in.

Visitor Surveys

An average of 2.4% of all visitors recorded from 1985 through 1987 (*n* = 7100 visitors) were involved in activities I considered to be potentially disturbing to raptors (Table 2), mostly off-road vehicle use and shooting. The main recreation of visitors was fishing (36.6% of all visitors), followed by people driving their vehicles (21.2%), and sightseeing (15.0%). Other observed activities were camping (6.5%), birdwatching (3.4%), and boating (both motorized and non-motorized, 4.6%). Use patterns were similar among years (Table 2). The number of visitors recorded during visitor surveys was always higher in the construction study location than in the recreation study location during both weekdays and weekends (Duncan's multiple range test (DMR), $P = 0.05$; Table 8). Average numbers of visitors recorded per weekday were not different among years. For weekend days, the highest numbers of visitors were recorded in 1985 (60.4 visitors/day), which were similar to 1987, but lower than in 1986 (46.0 and 36.6 visitors/day, respectively; DMR, $P = 0.05$). When weekdays and weekend days were pooled, numbers of visitors did not differ among years (23.1, 18.2, and 20.1 visitors/day for 1985, 1986, and 1987, respectively) (DMR, $P = 0.05$; Table 8). Most vehicles ($n = 3076$) carried Idaho license plates (94.3%, $n = 2902$), predominantly from Ada (68.1%) and Canyon (13.2%) counties (Table 9). The remaining in-state vehicles (13.0%) carried license plates of at least 27 other Idaho counties. Out-of-state license plates comprised 5.7% of all recorded plates, with Oregon, California, and Utah recorded most frequently (24.7, 14.3, and 12.1% of all out-of-state vehicles, respectively $n = 174$). Vehicle occupancy averaged 2.7 ± 2.0 persons/vehicle ($n = 2674$), including 2.0 adults, 0.6 children, and 0.1 persons older than 65 years per vehicle. Males comprised 67% of all visitors. Visitor numbers averaged 8,000 over the period from late March through June based on traffic flow data corrected for residential and construction traffic. Visitor numbers were estimated at 11,000 in 1987 and at 6,000, 8,000, and 7,000 in 1984, 1985, and 1986, respectively.

Human Activities Observed from Blinds

Activities of visitors recorded by observers in blinds ($n = 3628$ visitors) differed from those recorded during visitor surveys (Table 10). Sightseeing was the main activity (38.1%), followed by visitors driving their vehicles (10.7%), and birdwatching (9.3%). Activities considered disturbing to raptors amounted to 26.9%; ORV use, shooting, and rock throwing were most frequently recorded.

Classification of Aeries Exposed to Human Activities

Aeries were classified according to their exposure to 4 types of human activities: construction, recreation, controlled blasting, and minimal activities (i.e., control sites). However, the degree of exposure within each of the 4 groups varied. The question arose to what extent the 4 groups were distinct with respect to their exposure to human activities. Poor separation among the 4 groups would make analyses of the behavioral data less meaningful and the results ambiguous. Stepwise discriminant analysis showed that 5 indexes (i.e., the average number of visitors per day observed from blinds, the average traffic flows per day at traffic counters

Table 8. Visitors per day weighted by their activity recorded during visitor surveys, March-June 1985-1987 (*n* denotes numbers of days).

		Weekday			Weekend			Overall		
Year	Study location	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
1985	Construction	6.5	10.3	64	43.9	31.1	25	23.1 a*	31.8	89
	Recreation	2.2	4.1	64	16.5	11.8	25			
	Total	8.7	11.0	64	60.4	37.3	25			
1986	Construction	6.2	12.0	50	25.6	21.8	26	18.2 a	22.6	76
	Recreation	2.5	3.8	50	11.0	9.4	26			
	Total	8.7	13.1	50	36.6	25.9	26			
1987	Construction	5.7	7.3	70	27.1	20.3	30	20.1 a	26.2	100
	Recreation	3.2	3.9	70	18.9	15.0	30			
	Total	8.9	9.8	70	46.0	33.5	30			

* Means followed by the same letter(s) do not differ significantly at $P = 0.05$, based on Duncan's multiple range test.

Table 9. Origins of vehicles based on license plates recorded during visitor surveys in the BOPA, March-June 1985-1987 (*n* denotes numbers of vehicles).

	1985		1986		1987		1985-87	
Place of origin	%	*n*	%	*n*	%	*n*	%	*n*
Ada	64.4	677	64.1	398	72.5	1018	68.1	2093
Canyon	14.9	157	12.4	77	12.2	171	13.2	405
Valley	0.0	0	1.1	7	0.0	0	0.2	7
Owyhee	1.3	14	1.0	6	1.2	17	1.2	37
Latah	0.0	0	1.0	6	0.0	0	0.2	6
Boise	1.8	19	1.0	6	0.0	0	0.8	25
Twin Falls	1.6	17	0.0	0	1.1	15	1.0	32
Adams	1.2	13	0.0	0	0.0	0	0.4	13
Elmore	1.1	11	0.0	0	1.0	14	0.8	25
Other counties	8.1	85	12.3	77	6.9	97	8.4	259
Subtotal Idaho	94.4	993	92.9	577	94.9	1332	94.3	2902
Out-of-State	5.6	59	7.1	44	5.1	71	5.7	174
Total	100.0	1052	100.0	621	100.0	1403	100.0	3076

Table 10. Recreational activities recorded by observers in blinds in the BOPA, March-June 1985-1987 (*n* denotes numbers of visitors).

	1984		1985		1986		1987		1984-87	
Activity	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*
Sightseeing	58.5	272	36.6	395	34.7	268	34.0	446	38.1	1381
Moving vehicle	0.0	0	1.7	18	4.1	32	25.7	337	10.7	387
Birdwatching	14.0	65	16.3	176	6.1	47	3.9	51	9.3	339
Fishing	0.0	0	0.9	10	18.6	144	0.0	0	4.2	154
Boating (motor)	0.0	0	1.9	20	0.0	0	0.1	1	0.6	21
In parked vehicle	0.0	0	0.6	6	0.3	2	0.0	0	0.2	8
Camping	0.0	0	0.1	1	0.0	0	0.0	0	0.02	1
Boating (no motor)	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0
Outfitter	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0
Other	0.4	2	8.9	96	14.7	114	11.4	149	10.0	361
Subtotal	72.9	339	67.0	700	78.5	607	75.1	984	73.1	2652
ORV	0.0	0	2.7	29	7.9	61	16.7	219	8.5	309
Shooting	14.0	65	11.3	122	5.2	40	4.8	63	8.0	290
Rock throwing	11.6	54	15.4	167	5.6	43	2.5	33	8.2	297
Climbing cliff	1.5	7	1.5	16	1.4	11	0.7	10	1.2	44
Other disturbance	0.0	0	2.1	23	1.4	11	0.2	2	1.0	36
Subtotal	27.1	126	33.0	357	21.5	166	24.9	327	26.9	976
Total		465		1079		773		1311		3628

nearest to the ranked aerie, the total number of explosions each aerie had been exposed to, the total number of people per day recorded during a weekend survey, and the distance from the aeries to the nearest road) best described a separation among the 4 study locations. Average squared canonical correlation coefficient (ASCC) values close to 1 indicate substantial differences among study locations and close to 0 negligible differences. The high value of the ASCCs (ASCC = 0.87, $P < 0.0001$) strongly suggests that the 4 groups were well separated. Canonical discriminant function analysis was applied for a more detailed quantification. This analysis is a dimension-reduction technique related to principal component analysis and canonical correlation. The analysis derives a set of linear combinations of the quantitative variables that best summarize between-group variation. The group separation is graphically illustrated by the canonical scores for each of the aeries plotted on the 1st and 2nd canonical discriminant function (Fig. 3).

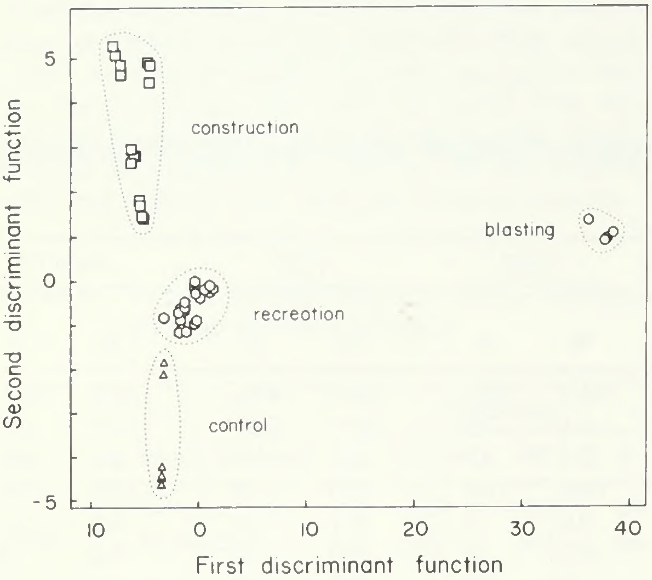


Fig. 3 Human activity scores of nesting territories observed in 1984-1987 plotted on the 1st and 2nd discriminant function.

Behavioral Repertoire of Falcons

During pre-incubation males perched and preened an average 15.9% of the day and females 43.6% (Table 11 A). Females were present in the nesting territory an average 84.8% of the day, whereas males were only observed for an average 37.5% of the day. Females spent a considerable amount of time inside the aerie, particularly about 9 days before incubation, when they started laying (Fig. 4). Males incubated an average 33.3% of the day and females 62.2% (Table 11 B). However, much variation was found in incubation time for male falcons. Some males incubated the same amount of time as females during the day, whereas others incubated mainly when females were consuming delivered prey. Males spent less time out-of-the canyon or out-of-view during incubation ($\bar{x}$ = 41.5%) than during pre-incubation (62.5%). Females spent about the same amount of time away from the nesting territory during incubation and pre-incubation. They increased their time away from the nesting territory as incubation progressed, although this trend was reversed during the last week of incubation (Fig. 4). Females apparently incubated at night because they were usually inside the aerie when observations terminated in the evening (267 of 287 cases). In falcon pairs that completed their clutch prior to 15 April, males spent 70.3% of the day outside the canyon and females 3.6%. In pairs completing their clutch after 15 April, however, males spent an average 59.7% outside the canyon and females 20.8%.

Brooding was mainly done by the female (23.0% of the day averaged over the entire brood-rearing stage); males played a minor role, at most 3.1% of the day (Table 11 C, Fig. 4). Percent brooding per day decreased sharply during the first 2 weeks of brood-rearing (Fig. 4). Young were rarely brooded during the day after they were 15 days of age. Brooding ceased at night after the young were 17 days old (SD = 4, n = 46 broods), although females usually positioned themselves in the entrance to the aerie. Both males and females perched and preened for a considerable proportion of the day (21.6 and 30.7%, respectively). Males spent an average 62.5% of the day out-of-the canyon or out-of-view. Females spent only 5-10% of the day away from the nesting territory during the first 2 weeks of brood-rearing, but this increased up to 35% of the day towards the end of the brood-rearing stage.

Falcon pairs that failed in their nesting attempt were absent (i.e., out-of-view or out-of-canyon) from the nesting territory most of the day (63.5% and 53.7% for males and females, respectively). They also perched, preened, and were out-of-view in the canyon for substantial parts of the day (36.6% and 42.8%, for males and females, respectively; Table 11 D). One week after failure of a nesting attempt either one or both adults were absent from the nesting territory, particularly when failure took place during brood-rearing (1-2 weeks, for 4 pairs). One pair (Halverson Upper Lake) copulated up to 28 days after a 2nd nesting attempt failed. The last observed prey delivery from the male to the female was 14 days after failure. Only the male was present in the nesting territory 35 days after failure.

Table 11. Behavioral time budget (behaviors expressed as percentages of total daily observation time, not transformed) for male and female prairie falcons (52 pairs) during (A) pre-incubation, (B) incubation, (C) brood-rearing, and (D) post-failure stages, 1984-1987.

A. Pre-incubation (*n* = 91 days)

	Male			Female		
Behavior	Mean	SD	Range	Mean	SD	Range
Perching	15.9	12.1	0.0 - 59.7	43.6	18.0	0.8 - 83.3
Preening	3.8	4.2	0.0 - 17.7	5.7	5.3	0.0 - 20.9
In scrape	3.2	8.2	0.0 - 54.6	16.8	20.7	0.0 - 71.6
Flight-in-canyon	2.7	2.7	0.0 - 14.3	1.4	1.4	0.0 - 8.0
Out-of-canyon	51.9	22.1	2.2 - 98.3	10.5	13.9	0.0 - 62.5
Out-of-view	10.6	12.3	0.0 - 61.3	4.7	10.4	0.0 - 60.4
Out-of-view in-canyon	8.1	7.8	0.0 - 38.5	10.7	12.5	0.0 - 65.5

B. Incubation (*n* = 267 days)

	Male			Female		
Behavior	Mean	SD	Range	Mean	SD	Range
Perching	8.8	7.6	0.0 - 50.2	8.6	8.5	0.0 - 54.5
Preening	5.8	4.9	0.0 - 22.1	6.0	5.4	0.0 - 26.0
Incubating	33.3	14.6	0.0 - 75.9	62.2	14.6	16.4 - 99.6
Flight-in-canyon	1.4	1.1	0.0 - 8.1	1.0	1.0	0.0 - 6.2
Out-of-canyon	31.7	18.2	0.0 - 81.3	11.9	12.2	0.0 - 68.4
Out-of-view	9.8	12.9	0.0 -100.0	3.3	6.5	0.0 - 41.2
Out-of-view in-canyon	6.5	7.1	0.0 - 42.3	4.0	5.5	0.0 - 32.0

C. Brood-rearing (*n* = 255 days)

	Male			Female		
Behavior	Mean	SD	Range	Mean	SD	Range
Perching	16.8	11.4	0.0 - 57.7	25.9	17.4	0.9 - 82.9
Preening	4.8	4.4	0.0 - 24.7	4.8	4.3	0.0 - 22.6
Brooding	3.1	6.5	0.0 - 47.1	23.0	30.7	0.0 - 91.1
Flight-in-canyon	1.9	1.7	0.0 - 12.0	1.7	1.5	0.5 - 8.2
Out-of-canyon	51.9	20.5	0.0 - 99.4	23.7	21.5	0.0 - 88.0
Out-of-view	10.6	16.4	0.0 -100.0	5.3	9.2	0.0 - 50.0
Out-of-view in-canyon	6.9	7.6	0.0 - 47.6	6.3	8.7	0.0 - 53.7

D. Post-failure (*n* = 19 days)

	Male			Female		
Behavior	Mean	SD	Range	Mean	SD	Range
Perching	19.6	24.1	0.0 -100.0	27.1	20.2	0.0 - 64.2
Preening	3.7	5.0	0.0 - 16.4	5.1	4.9	0.0 - 16.6
In scrape	0.5	1.1	0.0 - 2.5	1.1	2.5	0.0 - 5.5
Flight-in-canyon	1.8	1.6	0.0 - 5.0	1.2	0.7	0.0 - 2.6
Out-of-canyon	36.4	26.2	0.0 - 97.3	38.3	26.5	0.0 - 80.7
Out-of-view	27.1	34.7	0.0 -100.0	15.4	27.6	0.0 -100.0
Out-of-view in-canyon	13.3	12.2	0.0 - 38.3	10.6	7.8	0.0 - 26.2

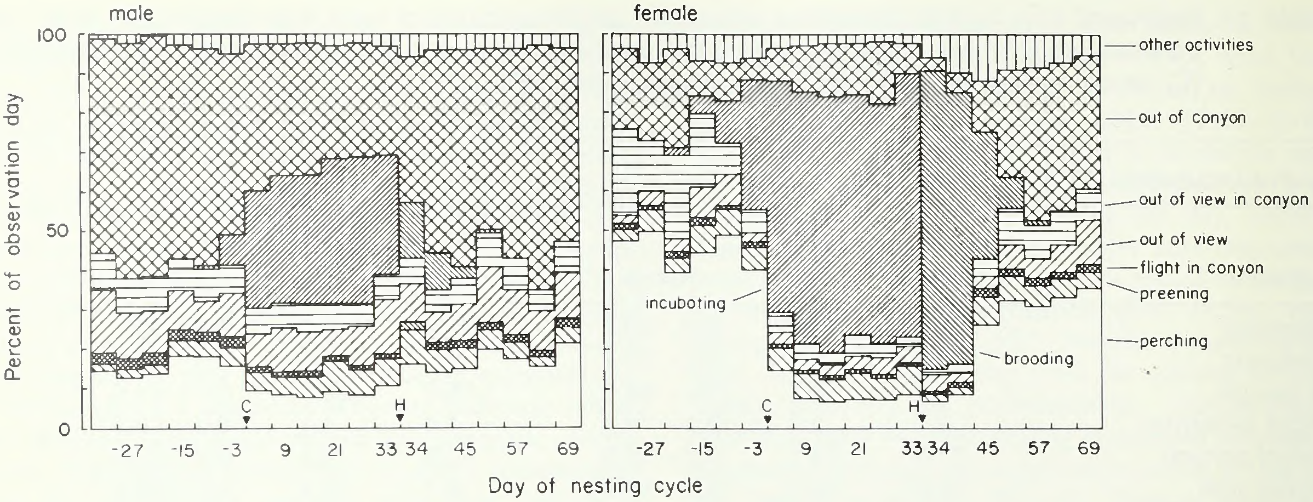


Fig. 4 Behavioral repertoire of prairie falcons, 1984-1987 (C = clutch completion; H = hatch).

Associations Between Human Activity and Falcon Behaviors

Three factors were extracted for male and female falcons when behavioral data expressed in percentages of total observation time per day or counts per day were analyzed (Tables 12 and 13). For the female prairie falcon, "traffic" showed a positive association with percent of time out-of-canyon, number of nest visits, and number of prey deliveries during pre-incubation and again with percent of time out-of-canyon behavior during incubation. "People" was negatively associated with aggression during pre-incubation and with relocations and feeding adult during brood-rearing. Both disturbance indexes were positively associated with patrolling during incubation and brood-rearing. For the male prairie falcon, "people" was positively associated with feeding adult and prey deliveries, and "traffic" with patrolling and nest visits during pre-incubation. Aggression and relocation had negative associations with "traffic" during incubation. During brood-rearing, "traffic" and "people" showed a negative association with patrolling. An increase in "traffic" and "people" were associated with an increase in brooding.

Table 12. Factor matrix for human activity variables and behaviors of male and female prairie falcons (expressed as percentages of total observation time/day) for (A) pre-incubation, (B) incubation, and (C) brood-rearing stages, 1985-1987 (*n* denotes the number of observation days).

A. Pre-incubation (*n* = 89 days)

	Male				Female			
Variables	I	II	III	h^2	I	II	III	h^2
People	0.08	0.77	0.05	0.59	-0.26	0.70	-0.13	0.57
Traffic	0.31	-0.58	0.44	0.62	0.80	0.02	0.12	0.64
Perching	0.70	-0.16	-0.48	0.74	-0.05	-0.16	0.85	0.74
Preening	0.74	0.09	-0.29	0.64	-0.02	0.28	0.62	0.46
In scrape	0.10	0.75	0.05	0.57	-0.60	0.66	-0.17	0.82
Canyon flight	0.65	0.31	0.12	0.53	0.23	0.30	0.15	0.16
Out-of-view	0.01	0.03	0.88	0.78	-0.20	-0.73	-0.29	0.65
Out-of-canyon	-0.83	-0.14	-0.26	0.77	0.67	-0.11	-0.41	0.63
Out-of-view in-canyon	0.52	-0.22	0.09	0.32	0.81	0.03	-0.09	0.67
% variance	28.2	18.5	15.3		25.1	18.4	16.0	

Table 12. *continued*

B. Incubation (*n* = 227 days)

	Male				Female			
Variables	I	II	III	*h*²	I	II	III	*h*²
People	0.01	-0.04	0.53	0.28	0.16	-0.04	0.66	0.46
Traffic	0.06	0.09	0.69	0.48	-0.23	-0.54	0.49	0.58
Perching	-0.61	-0.27	-0.34	0.56	-0.38	0.56	0.11	0.46
Preening	-0.41	-0.54	-0.23	0.51	-0.15	0.78	0.07	0.63
In scrape	-0.26	-0.73	0.40	0.76	0.83	-0.14	-0.30	0.80
Canyon flight	-0.59	-0.09	-0.10	0.36	-0.57	-0.09	-0.09	0.33
Out-of-view	0.89	-0.09	-0.14	0.82	-0.01	0.22	0.71	0.54
Out-of-canyon	-0.14	0.90	0.22	0.87	-0.51	-0.68	-0.10	0.73
Out-of-view in-canyon	-0.37	-0.15	-0.51	0.41	-0.56	0.10	-0.18	0.35
% variance	21.2	19.5	15.7		20.2	19.5	14.8	

C. Incubation (*n* = 208 days)

	Male				Female			
Variables	I	II	III	*h*²	I	II	III	*h*²
People	-0.06	0.15	0.55	0.32	0.15	-0.02	0.69	0.49
Traffic	-0.32	-0.48	0.55	0.63	-0.07	-0.01	0.25	0.06
Perching	0.79	0.05	-0.06	0.63	0.35	0.77	0.16	0.73
Preening	0.61	0.32	0.09	0.48	-0.09	0.83	0.03	0.69
In scrape	0.13	-0.02	0.59	0.36	-0.85	-0.46	-0.15	0.94
Canyon flight	0.72	-0.23	-0.05	0.57	0.09	0.57	-0.11	0.34
Out-of-view	-0.20	0.86	0.01	0.78	-0.02	0.09	0.80	0.65
Out-of-canyon	-0.52	-0.60	-0.45	0.83	0.89	-0.10	0.01	0.79
Out-of-view in-canyon	0.57	-0.28	0.44	0.60	0.56	0.18	-0.38	0.49
% variance	25.3	17.7	15.2		21.9	20.8	15.2	

Table 13. Factor matrix for human activity variables and behaviors of male and female prairie falcons (expressed as counts/day) for (A) pre-incubation, (B) incubation, and (C) brood-rearing stages, 1985-1987 (*n* denotes the number of observation days).

A. Pre-incubation (*n* = 89 days)

	Male				Female			
Variables	I	II	III	*h*²	I	II	III	*h*²
People	0.01	0.76	0.04	0.57	0.12	-0.21	0.86	0.80
Traffic	0.17	-0.51	0.71	0.78	0.09	0.69	-0.22	0.53
Patrolling	0.61	0.03	0.56	0.68	-0.01	-0.05	-0.35	0.12
Aggression	0.69	0.12	0.07	0.50	0.50	-0.31	-0.50	0.60
Copulation	0.73	0.01	0.04	0.53	0.74	0.13	0.17	0.59
Nest visit	0.08	0.14	0.66	0.45	0.13	0.65	0.26	0.51
Relocation	0.91	0.01	0.02	0.83	0.80	0.11	-0.36	0.77
Feeding adult	0.34	0.67	0.02	0.56	0.63	0.06	0.14	0.42
Prey delivery	-0.25	0.51	0.53	0.59	0.01	0.83	0.01	0.69
% variance	26.9	17.4	17.0		20.8	19.7	15.7	

Table 13. *continued*

B. Incubation (n = 227 days)

	Male				Female			
Variables	I	II	III	h^2	I	II	III	h^2
People	-0.37	0.15	-0.02	0.16	-0.06	0.54	-0.37	0.42
Traffic	-0.77	-0.03	0.19	0.63	-0.06	0.77	0.01	0.59
Patrolling	0.07	0.61	0.05	0.37	0.48	0.54	0.23	0.57
Aggression	0.56	0.40	0.25	0.53	0.59	-0.10	0.08	0.36
Copulation	-0.08	0.37	-0.46	0.35	0.40	0.11	-0.47	0.38
Nest visit	0.15	-0.11	0.53	0.31	-0.05	0.20	-0.45	0.24
Relocation	0.71	0.16	0.26	0.60	0.78	-0.16	-0.07	0.63
Feeding adult	-0.16	0.34	0.74	0.69	0.65	0.21	0.04	0.46
Prey delivery	-0.01	0.74	-0.11	0.55	0.14	0.28	0.68	0.56
% variance	17.9	15.4	13.6		19.9	15.3	12.0	

C. Brood-rearing (n = 208 days)

	Male				Female			
Variables	I	II	III	h^2	I	II	III	h^2
People	0.28	0.02	0.70	0.57	0.05	-0.54	0.52	0.56
Traffic	-0.11	0.11	0.58	0.36	-0.15	0.01	0.70	0.51
Patrolling	0.45	0.13	-0.55	0.51	0.21	0.20	0.55	0.37
Aggression	0.71	-0.04	0.05	0.50	0.54	0.02	-0.09	0.30
Copulation	-0.05	0.69	0.21	0.52	0.56	-0.05	-0.05	0.31
Nest visit	0.28	0.67	-0.15	0.55	0.66	-0.18	0.19	0.51
Relocation	0.64	0.52	0.04	0.68	0.66	0.58	0.10	0.78
Feeding adult	0.66	-0.07	-0.10	0.44	-0.13	0.77	0.20	0.65
Prey delivery	0.36	-0.56	-0.02	0.45	0.36	-0.30	-0.37	0.35
% variance	20.6	17.2	13.4		18.9	15.4	14.3	

Differences in Falcon Behaviors Among Study Locations

Stepwise discriminant analysis was employed to test for differences among the 4 study locations for behaviors expressed in percentages of total observation time per day and counts per day. The analyses were carried out separately for males and females and for each of the nesting stages (except post-failure) with behavioral data pooled over all field seasons. The consistently low ASCCs suggested poor discrimination among the 4 study locations (ASCCs < 0.10, Table 14). Similar results were found when discriminant analyses were conducted on the behavioral data expressed in counts per day (Table 15). Again, the low ASCC values (ASCCs < 0.11) suggest negligible differences in behavior among the 4 study locations.

Analyses of Individual Behaviors

Separate univariate analyses were conducted with behaviors that were considered critical in the nesting cycle and sensitive to human activities. The analyses also served to address the trends that emerged from the factor analysis.

Copulation

Copulations averaged 3.8 ± 2.8 per day (n = 91 days) during pre-incubation, sharply declined during the 1st week of incubation to 0.2 ± 0.6 per day (n = 267 days), and increased slightly to 0.6 ± 1.2 per day (n = 255 days) during brood-rearing (Fig. 5). The diurnal distribution of copulations showed a peak in the early morning hours (0 to 2 hours after sunrise), and a 2nd,

Table 14. Stepwise discriminant analysis to test for differences in behaviors of male and female prairie falcons (expressed as percentages of total observation time/day) among the 4 study locations for pre-incubation, incubation, and brood-rearing stages, 1984-1987 (*n* denotes numbers of observation days). Only *P*-values < 0.10 are included.

	Pre-incubation (n = 91)						Incubation (n = 267)						Brood-rearing (n = 255)					
	Male			Female			Male			Female			Male			Female		
Variables	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2
Perching	-	-	-	-	-	-	6.25	<0.01	0.06	-	-	-	6.85	<0.01	0.07	-	-	-
Preening	-	-	-	-	-	-	-	-	-	5.47	<0.01	0.06	5.52	<0.01	0.06	-	-	-
In aerie	2.98	0.05	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Incubating	-	-	-	-	-	-	2.98	0.03	0.03	3.45	0.01	0.03	-	-	-	-	-	-
Brooding	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Canyon flight	4.49	0.01	0.09	3.74	0.02	0.07	2.23	0.08	0.02	3.75	0.01	0.04	4.14	<0.01	0.04	3.82	0.01	0.04
Out-of-view	-	-	-	-	-	-	5.93	<0.01	0.06	8.06	<0.01	0.08	9.43	<0.01	0.10	6.81	<0.01	0.07
Out-of-canyon	-	-	-	-	-	-	10.30	<0.01	0.10	2.97	0.03	0.03	4.18	<0.01	0.04	-	-	-
Out-of-view in-canyon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ASCC		0.10			0.03			0.09			0.09			0.07			0.05	

Table 15. Stepwise discriminant analysis to test for differences in behaviors of male and female prairie falcons (expressed as counts/day) among the 4 study locations for pre-incubation, incubation, and brood-rearing stages, 1984-1987 (*n* denotes numbers of observation days). Only *P*-values <0.10 are included.

	Pre-incubation (n = 91)						Incubation (n = 267)						Brood-rearing (n = 255)					
	Male			Female			Male			Female			Male			Female		
Variables	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2
Nest visit	-	-	-	-	-	-	-	-	-	-	-	-	3.38	0.01	0.04	5.95	<0.01	0.06
Patrolling	7.47	<0.01	0.14	7.17	<0.01	0.14	3.48	0.01	0.03	-	-	-	7.07	<0.01	0.08	9.71	<0.01	0.10
Aggression	-	-	-	-	-	-	3.99	<0.01	0.04	3.71	0.01	0.04	2.81	0.03	0.03	3.05	0.02	0.03
Copulation	-	-	-	-	-	-	-	-	-	-	-	-	2.27	0.07	0.02	2.38	0.06	0.02
Relocation	-	-	-	-	-	-	6.08	<0.01	0.06	-	-	-	6.66	<0.01	0.07	6.77	<0.01	0.07
Feeding	-	-	-	2.79	0.06	0.06	-	-	-	-	-	-	-	-	-	3.64	0.01	0.04
Prey delivery	2.96	0.05	0.06	-	-	-	2.14	0.09	0.02	-	-	-	-	-	-	-	-	-
ASCC		0.11			0.09			0.05			0.01			0.05			0.07	

minor peak in late afternoon to early evening (11 to 12.5 hours after sunrise) (Fig. 6). Copulation frequencies varied considerably among years, study locations, nesting stages, and nesting territories (ANOVA, F = 12.77, df = 3 and 559, P = 0.0001; F = 5.05, df = 3 and 559, P = 0.0001; F = 283.18, df = 2 and 559, P = 0.0001; and F = 2.02, df = 45 and 559, P = 0.0002, respectively). The highest copulation frequencies were recorded in 1987 (1.4 ± 2.2 per day, n = 163). The years 1985 (0.7 ± 1.7 per day, n = 207) and 1986 (0.9 ± 1.9 per day, n = 154) both showed significantly lower copulations frequencies than 1987 (DMR, P = 0.05). Copulation frequencies recorded in 1984 (0.5 ± 1.1 per day, n = 89) were similar to those recorded in 1985. Copulation frequencies were significantly lower in the blasting study location than in the 3 BOPA study locations, which did not differ (DMR, P = 0.05). Behavioral observations in the blasting study location started during early to mid-incubation, which may explain the low copulation frequency reported. During pre-incubation, copulation frequencies were similar among the 4 years and among the study locations (DMR, P = 0.05).

The average daily copulation rate per nesting pair increased with human activity as expressed by the rank sum for each nesting attempt (Kendall's coefficient of rank correlation, r_T = 0.21, P = 0.02, n = 54 nesting attempts).

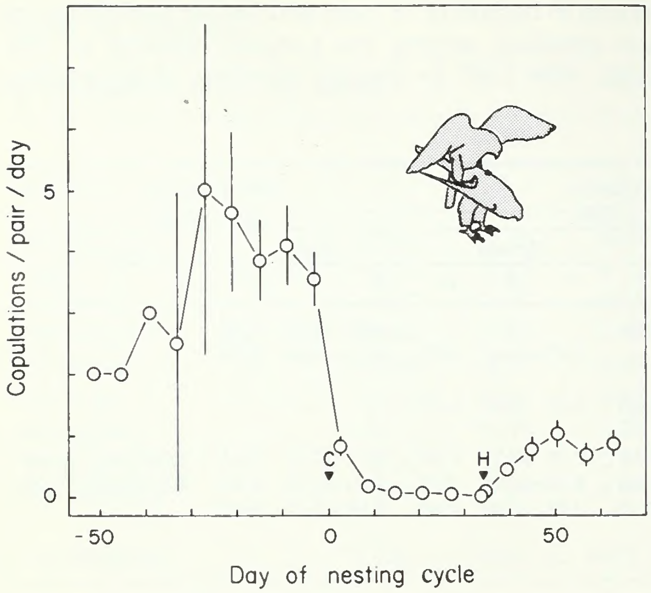


Fig. 5 Average number of copulations/day of prairie falcon pairs, 1984-1987.

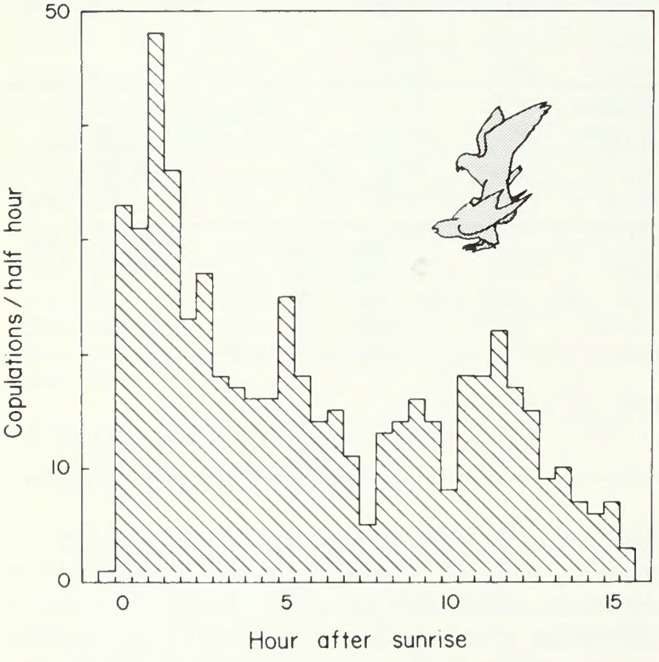


Fig. 6 Diurnal distribution of the number of copulations/day of prairie falcon pairs, 1984-1987.

Incubation

One week to 10 days prior to incubation, both sexes spent increasingly longer periods of time inside the aerie, although the female was in the aerie more than the male (Fig. 7). The percent of the observation day spent incubating per pair followed a sigmoid curve, levelling off at about 97% of the day towards the end of the 1st week of incubation (Fig. 7). During a nest exchange, eggs were unattended for an average 3.8 ± 0.5 (SE) min (range = 0-22 min, n = 223 nest exchanges; 10.5 ± 0.3 (SE) nest exchanges per day (n = 267 days) took place.

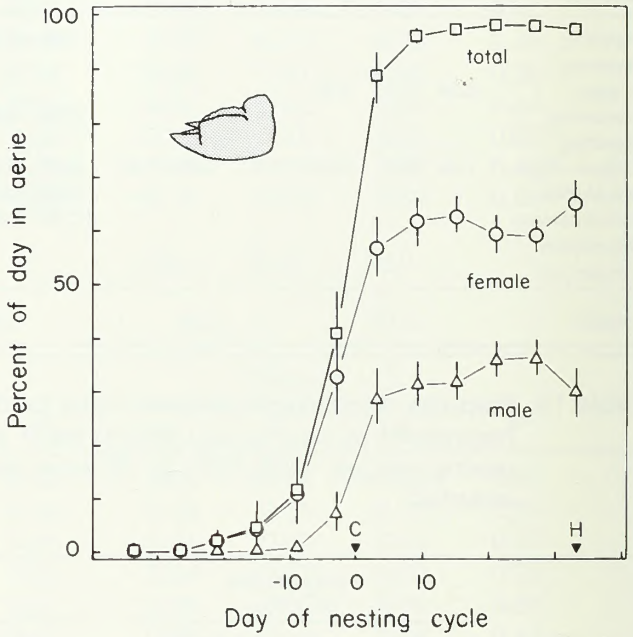


Fig. 7 Percent of the day incubating by male and female prairie falcons, 1984-1987.

The incubation data were analyzed in 2 ways. First, average percent of the day incubating/pair was used in analyses for comparisons among years, study locations, and nesting pairs. Second, percent of the day incubating/pair regressed on day of incubation followed by an analysis of covariance was used to test for differences among years and study locations. Years and nesting pairs differed significantly in average percent of the day incubating (ANOVA, F = 9.37, df = 3 and 213, P = 0.0001; and F = 1.92, df = 44 and 213, P = 0.001, respectively), but percent of the day incubating was similar among the 4 study locations (F = 0.72, df = 3 and 213, P = 0.54). Average percent of the day incubating per pair was lower in 1986 than in 1984, 1985, and 1987 (94.3%, 97.4%, 96.7%, and 98.8%, respectively; DMR, P = 0.05). When percent of the day incubating was compared among nesting pairs for each of the years, differences were found for 1986 and 1987. In 1986, 2 nesting pairs (Falcon Flats Black Rock and Halverson Upper Lake) spent less time per day incubating than other pairs that year (DMR, P = 0.05).

Likewise, in 1987, 1 nesting pair (Halverson Dunes) spent a smaller percent of the day incubating than other pairs that year (DMR, $P = 0.05$). All 3 pairs failed in their nesting attempts. Differences were not found in average percent of the day incubating among study locations for each of the years 1984-1986 (ANOVA, $F = 1.52$, df = 1 and 35, $P = 0.22$; $F = 0.39$, df = 3 and 82, $P = 0.76$; and $F = 0.31$, df = 2 and 68, $P = 0.73$, respectively). In 1987, however, average percent of the day incubating was slightly higher in the construction study location than in the recreation and control study locations (98.7%, 97.5%, and 97.3%, respectively; DMR, $P = 0.05$).

Analysis of covariance was used to compare percent of the day incubating among study locations for all years combined and among study locations for each year separately. Percent of the day incubating was regressed on day of incubation. Differences were not found among study locations (ANCOVA, $F = 0.01$, df = 3 and 256, $P > 0.10$; and $F = 0.34$, df = 3 and 256, $P > 0.10$, for testing equality of slopes and intercepts, respectively) when all years were pooled. Likewise, percent of the day incubating over time was similar among study locations for 1985, 1986, and 1987 (ANCOVAs, P's > 0.10). In 1984, however, percent of the day incubating was higher in the recreation than the construction study location (ANCOVA, $F = 6.05$, df = 1 and 82, $P < 0.01$). The slopes of these regression lines were similar (partial $F = 3.16$, df = 1 and 82, $0.20 < P < 0.50$).

The average amount of time per day that eggs were unattended differed among years and nesting pairs (ANOVA, $F = 5.86$, df = 3 and 216, $P = 0.\ 0007$; and $F = 2.73$, df = 44 and 216, $P = 0.0001$), but not among study locations ($F = 1.38$, df = 3 and 216, $P = 0.24$). The longest nest exchanges were recorded in 1986 and 1985 (6.2 ± 11.9 min/nest exchange, $n = 71$ days and 4.1 ± 7.0 min/nest exchange, $n = 86$ days, respectively) and shortest in 1984 and 1987 (2.4 ± 2.0 min/nest exchange, $n = 38$ days and 1.9 ± 1.7 min/nest exchange, $n = 72$ days, respectively). The number of nest exchanges per day remained relatively constant during incubation and ranged from 10.0 ± 4.7 per day ($n = 48$) on the 9th day of incubation to 11.7 ± 5.0 per day ($n = 31$) on the 33rd day of incubation.

Brooding

Shortly after hatch, young were brooded most of the day (89.0 ± 10.7%, $n = 12$ days), but this rapidly declined to 35.0 ± 25.6% of the day ($n = 45$ days) when young were 11 days old (Fig. 8). Young 15 days of age were brooded for only 8.5 ± 12.0% of the day ($n = 44$ days). Females did most of the brooding during the day (Fig. 8) and almost all of the brooding at night (123 of 124 instances). Percent of the day brooding decreased with increasing age of the young and with increasing ambient temperature (partial $b = -0.039$, $t = -24.09$, $P < 0.0001$; and partial $b = -0.006$, $t = -1.84$, $P = 0.06$, respectively). Precipitation, however, did not show a relationship with percent of the day brooding (partial $b = 0.002$, $t = 0.47$, $P = 0.63$). Analysis of covariance was employed to compare percent of the day brooding among years (study locations pooled) and among study locations for each year. For this analysis, percent of the day brooding was regressed on the day of brood-rearing (days 34 through 57). Percent of the day brooding showed a similar decrease over time among years (ANCOVA, $F = 0.56$, df = 3 and 246, $P > 0.10$; and $F = 0.26$, df = 3 and 246, $P > 0.10$, to test for differences among slopes and intercepts, respectively), among study locations for all years pooled (ANCOVA, $F = 0.83$, df = 3 and 246, $P > 0.10$; and partial $F = 1.21$, df = 3 and 246, $P > 0.10$, to test for differences among slopes and intercepts, respectively), and among study locations for each year (ANCOVAs, P's > 0.10).

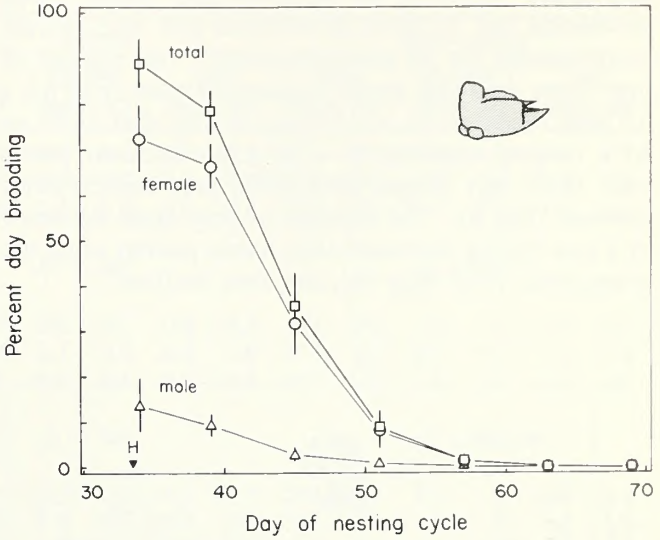


Fig. 8 Percent of the day brooding by male and female prairie falcons, 1984-1987.

Prey Delivery Rates

Overall, males delivered 76.0% of all prey (2.3 ± 2.1 prey items/day, $n = 613$ days) to the nesting territories during the nesting cycle. On average, prey delivery rates by male falcons were about 4 times higher during brood-rearing than during either pre-incubation or incubation

(Fig. 9). The male delivered an estimated 97.8% of all delivered prey items to the nesting territory during pre-incubation, 95.3% of all delivered prey items during incubation, and 70.2% of all delivered prey items during brood-rearing for all years combined. The number of prey items delivered by the female increased from 0.3 ± 0.5 prey items/day (*n* = 14 days) shortly after hatch to 3.0 ± 1.8 prey items/day (*n* = 45 days) when the young were 19-23 days of age, after which prey delivery rates declined (Fig. 9). The number of prey items delivered by a pair rapidly increased after hatch, peaked when the young were 19-25 days old, and then declined.

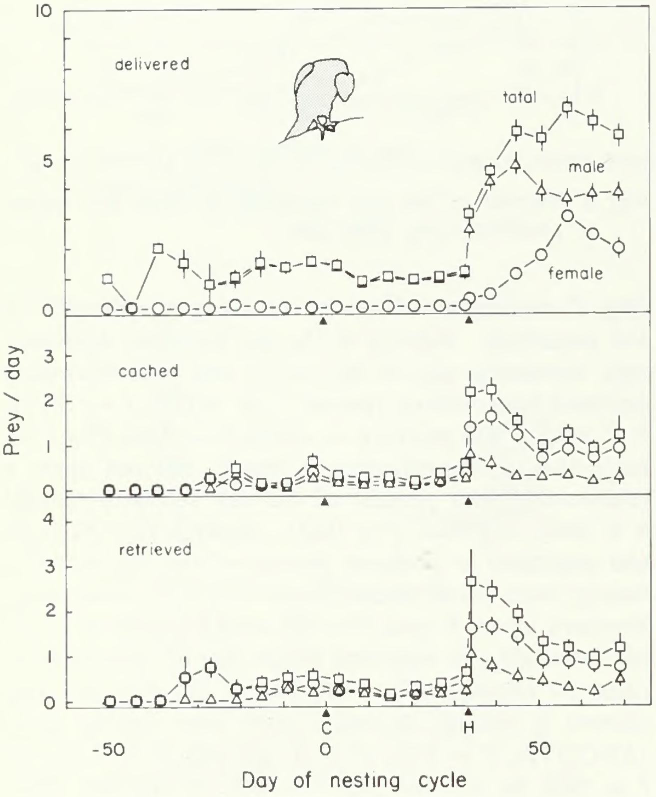


Fig. 9 Number of prey items delivered, cached, and retrieved per day by male and female prairie falcons, 1984-1987.

The number of prey items cached per day by the male and female was relatively small during both pre-incubation and incubation, but increased significantly during brood-rearing, in particular during the first 2 weeks (Table 16). The caching rate then declined and remained fairly constant through the rest of the observed brood-rearing stage (Fig. 9). The retrieval of prey items per day followed the same trends as noted for prey caching in both male and female falcons (Fig. 9). The prey delivery rate showed a peak in the morning (2-5 hours after sunrise) and a lesser peak in the late afternoon (12-13 hours after sunrise; Fig. 10). The caching of prey items during the day showed a similar distribution as described for prey deliveries (Fig. 10). The retrieval of prey items by both sexes was high around sunrise, declined through the morning, increased around midday, and remained at this level until late afternoon-early evening when retrieval rates peaked again (Fig. 10).

The prey delivery data were analyzed using 2 approaches. The effects of year, nesting stage, nesting pair, and study location were first investigated with the number of prey delivered per hour (i.e., the total number of fresh prey delivered/pair/day divided by the total number of observation hours per day). The same analyses were carried out with an index named "prey procurement time" which was calculated as the total time out-of-canyon/pair divided by the number of delivered prey/pair for each day. Analyses of covariance were conducted with total out-of-canyon time/pair/day regressed on the number of delivered prey/pair/day. Differences were found in the number of prey delivered/pair/h among years, nesting stages, and nesting pairs (ANOVA, F = 26.53, df = 3 and 559, $P < 0.0001$; F = 448.59, df = 2 and 559, $P < 0.0001$; and F = 3.41, 45 and 559, $P < 0.0001$, respectively), but not among study locations (F = 1.24, df = 3 and 559, P = 0.29). A comparison made among study locations for each year and nesting stage only shows differences for the incubation stage in 1985 and brood-rearing stage in 1987 (Table 17). In 1985 high hourly prey delivery rates during incubation were observed in the construction and recreation study locations (0.1 ± 0.7 prey items/h, *n* = 23 days, and 0.07 ± 0.05 prey items/h, *n* = 22 days, respectively), and low rates in the control and blasting study locations (0.05 ± 0.06 prey items/h, *n* = 20 days, and 0.04 ± 0.06 prey items/h, *n* = 21 days, respectively) (DMR, P = 0.05). In 1987 prey delivery rates in the construction study location (0.35 ± 0.15 prey items/h, *n* = 28 days) were significantly lower than in the recreation and control study locations (0.45 ± 0.13 prey items/h, *n* = 23 days, and 0.47 ± 0.19 prey items/h, *n* = 20 days). When nesting stages were pooled for each of the years, no differences were detected among study locations (Table 17). Prey delivery rates were similar among study locations for each nesting stage when years were analyzed collectively (pre-incubation: ANOVA, F = 2.45, df = 2 and 87, P = 0.10; incubation: ANOVA, F = 1.73, df = 3 and 264, P = 0.16; and brood-rearing: ANOVA, F = 1.69, df = 3 and 251, P = 0.16). Prey delivery rates did not differ among years for the pre-incubation stage (ANOVA, F = 0.09, df = 3 and 86, P = 0.96), but were different for the incubation and brood-rearing stages (ANOVA, F = 3.73, df = 3

Table 16. Numbers of prey items delivered*, cached, and retrieved per day by prairie falcon pairs (*n* = 52) for all study locations combined, 1984-1987 (*n* refers to numbers of days).

		Pre-incubation						Incubation						Brood-rearing					
		Male		Female		Total		Male		Female		Total		Male		Female		Total	
Year	Prey	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	Delivered	1.5	0.7	0.0	0.0	1.5	0.7	1.4	1.1	0.1	0.2	1.5	1.1	4.1	2.1	1.2	1.2	5.3	2.3
1984	Cached	0.5	0.7	0.5	0.7	1.0	0.1	0.1	0.4	0.2	0.6	0.3	0.7	0.3	0.6	0.9	1.2	1.2	1.5
	Retrieved	0.0	0.0	0.5	0.7	0.5	0.7	0.1	0.3	0.3	0.6	0.4	0.7	0.4	0.7	1.3	1.6	1.7	1.9
				(*n* = 2)						(*n* = 38)						(*n* = 49)			
	Delivered	1.4	0.9	0.0	0.0	1.4	0.9	0.9	0.9	0.0	0.2	0.9	0.9	3.9	2.0	1.8	1.7	5.7	2.4
1985	Cached	0.2	0.4	0.3	0.7	0.5	1.0	0.2	0.4	0.1	0.4	0.3	0.6	0.2	0.5	0.9	1.1	1.1	1.2
	Retrieved	0.2	0.4	0.5	0.8	0.7	1.0	0.1	0.3	0.2	0.5	0.3	0.6	0.3	0.7	1.0	1.1	1.3	1.5
				(*n* = 26)						(*n* = 86)						(*n* = 95)			
	Delivered	1.4	1.3	0.1	0.2	1.5	1.2	1.1	1.1	0.1	0.3	1.2	1.1	2.9	2.1	1.1	1.0	4.0	2.3
1986	Cached	0.1	0.3	0.2	0.4	0.3	0.5	0.1	0.4	0.3	0.5	0.4	0.7	0.2	0.4	1.1	1.1	1.3	1.0
	Retrieved	0.1	0.4	0.2	0.5	0.4	0.6	0.2	0.6	0.3	0.5	0.5	0.8	0.4	0.8	1.2	1.4	1.6	1.7
				(*n* = 43)						(*n* = 71)						(*n* = 40)			
	Delivered	1.2	1.1	0.1	0.3	1.3	1.1	0.9	0.9	0.1	0.3	1.0	1.0	4.4	2.1	2.1	1.8	6.5	2.6
1987	Cached	0.2	0.4	0.1	0.4	0.4	0.5	0.1	0.3	0.2	0.5	0.3	0.6	0.8	1.2	1.2	1.4	2.0	2.1
	Retrieved	0.2	0.5	0.3	0.6	0.5	1.0	0.1	0.4	0.1	0.5	0.3	0.7	0.8	1.3	1.0	1.1	1.9	1.7
				(*n* = 20)						(*n* = 72)						(*n* = 71)			
	Delivered	1.4	1.1	0.0	0.2	1.4	1.1	1.0	0.9	0.1	0.2	1.1	1.0	3.9	2.1	1.7	1.6	5.6	2.5
All	Cached	0.2	0.4	0.2	0.5	0.4	0.7	0.1	0.4	0.2	0.5	0.3	0.6	0.4	0.8	1.0	1.2	1.4	1.6
years	Retrieved	0.2	0.4	0.3	0.6	0.5	0.8	0.2	0.4	0.2	0.5	0.4	0.7	0.5	0.9	1.1	1.3	1.6	1.7
				(*n* = 91)						(*n* = 267)						(*n* = 255)			

* Freshly killed prey items that were brought to the nesting territory.

and 264, $P = 0.01$; and ANOVA, $F = 9.52$, df = 3 and 251, $P < 0.0001$). During incubation, the highest prey delivery rates were found in 1984, followed by 1986, 1985, and 1987 (0.11 ± 0.08, $n = 38$ days versus 0.08 ± 0.08, $n = 72$ days, 0.07 ± 0.06, $n = 86$ days, and 0.07 ± 0.07 prey items/hour, $n = 72$ days, respectively) (DMR, $P = 0.05$). For brood-rearing the highest prey delivery rates were observed in 1987, followed by 1985 and 1984 (0.41 ± 0.17 ($n = 71$ days) versus 0.36 ± 0.15 ($n = 95$ days) and 0.35 ± 0.15 prey items/hour ($n = 49$ days), respectively (DMR, $P = 0.05$). In 1986 prey delivery rates during brood-rearing were lower than in any of the other years (0.25 ± 0.14 prey items/hour, $n = 40$ days).

A significant relationship could not be demonstrated between the average prey delivery rate/pair/hour and the human activity index calculated for each nesting attempt ($r_T = 0.001$, $P = 0.98$, $n = 54$ nesting attempts).

The prey procurement time index (min/prey item) differed significantly among years, nesting stages, and nesting pairs (ANOVA, $F = 45.25$, df = 3 and 449, $P < 0.0001$; $F = 46.39$, df = 2 and 449, $P < 0.0001$; and $F = 3.35$, df = 45 and 449, $P < 0.0001$, respectively), but not among study locations ($F = 0.55$, df = 3 and 449, $P = 0.64$). Significant differences were found in prey procurement times among study locations for the incubation stage in 1986, and the brood-rearing stage in 1986 and 1987 (Table 18). During the incubation stage in 1986, high prey procurement times were recorded for the construction study location, and low values in the recreation and control study locations (DMR, $P = 0.05$). During the brood-rearing stage of the same year, however, a higher prey procurement time was found in the recreation study location than in the control and construction study locations (DMR, $P = 0.05$). In 1987, for the brood-rearing stage, a higher prey procurement time was found in the construction study location than in the recreation or control study locations (DMR, $P = 0.05$). Prey procurement times

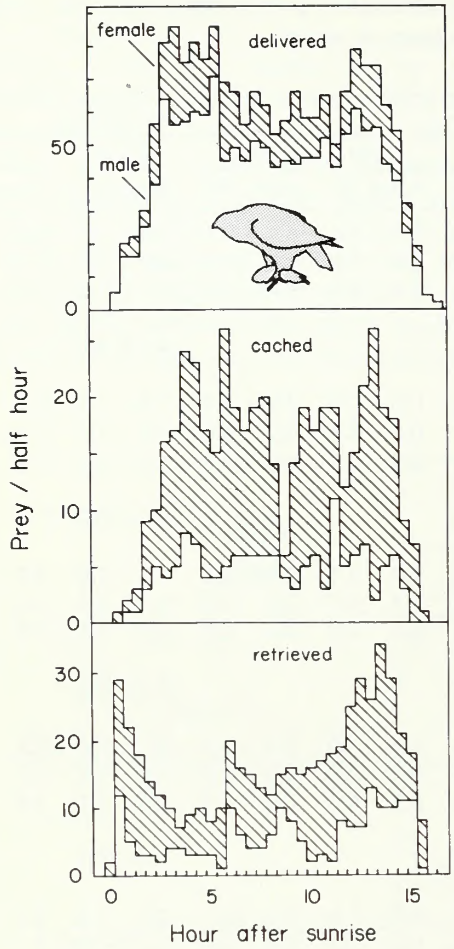


Fig. 10 Diurnal distribution of prey deliveries, caches, and retrievals by prairie falcon pairs, 1984-1987.

did not differ among study locations when years were pooled by nesting stage (pre-incubation: ANOVA, $F = 0.96$, df = 2 and 69, $P = 0.38$; incubation: ANOVA, $F = 2.16$, df = 3 and 172, $P = 0.10$; and brood-rearing: ANOVA, $F = 0.40$, df = 3 and 499, $P = 0.75$). Prey procurement time was different among years for each nesting stage (Table 19). During pre-incubation prey procurement time was higher in 1986 and 1984 than in 1987 and 1985 (DMR, $P = 0.05$). For the incubation stage prey procurement time was highest in 1986 and 1984, followed by 1985 and 1987 (DMR, $P = 0.05$). During brood-rearing the highest prey procurement time was recorded for 1986, followed by 1984 and 1985, which did not differ from each other; the lowest prey procurement time was found for 1987 (DMR, $P = 0.05$).

Out-of-canyon time per pair/day regressed on prey delivered per pair/day did not differ among the 3 BOPA study locations when all years were combined. However, pairs nesting in the blasting study location spent more time out-of-canyon than pairs nesting in each of the BOPA study locations (ANCOVA, slopes $F = 7.69$, df = 3 and 605, $P < 0.0001$, and intercepts $F = 3.73$, df = 3 and 605, $0.02 < P < 0.05$). The slopes of the regression lines for the 3 BOPA study locations were similar, but the slope of the regression line for the blasting study location was steeper (Tukey multiple comparison of slopes, $P = 0.05$).

Table 17. ANOVA's to test for differences in prey delivery rate/hour among study locations for each year and nesting stage (*n* refers to numbers of observation days).

					Construction			Recreation			Control			Blasting			Total		
Year	Nesting Stage	*F*	df	*P*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
	Pre-incubation	-	-	-	0.12	0.05	2	-	-	-	-	-	-	-	-	-			
1984	Incubation	0.80	1,36	0.37	0.12	0.07	22	0.09	0.09	16	-	-	-	-	-	-			
	Brood-rearing	0.34	1,47	0.56	0.34	0.16	25	0.37	0.14	24	-	-	-	-	-	-			
	Pooled	0.50	1,87	0.48	0.23	0.17	49	0.26	0.18	40	-	-	-	-	-	-	0.24	0.17	89
	Pre-incubation	0.38	2,23	0.68	0.12	0.09	8	0.09	0.05	9	0.10	0.07	9	-	-	-			
1985	Incubation	3.59	3,82	0.01	0.10	0.07	23	0.07	0.05	22	0.05	0.06	20	0.04	0.06	21			
	Brood-rearing	2.54	3,91	0.06	0.37	0.13	19	0.41	0.18	25	0.34	0.15	27	0.30	0.12	24			
	Pooled	0.55	3,203	0.64	0.21	0.17	50	0.23	0.21	56	0.20	0.18	56	0.18	0.16	45	0.20	0.18	207
	Pre-incubation	1.63	2,39	0.20	0.12	0.09	13	0.12	0.11	16	0.07	0.05	13	-	-	-			
1986	Incubation	0.24	2,69	0.78	0.08	0.06	25	0.08	0.08	22	0.09	0.09	25	-	-	-			
	Brood-rearing	1.84	2,37	0.17	0.27	0.11	12	0.19	0.14	13	0.29	0.15	15	-	-	-			
	Pooled	0.30	2,151	0.74	0.14	0.11	50	0.12	0.12	51	0.14	0.14	53	-	-	-	0.13	0.12	154
	Pre-incubation	1.00	2,17	0.38	0.11	0.05	2	0.12	0.09	10	0.07	0.06	8	-	-	-			
1987	Incubation	2.51	2,69	0.08	0.04	0.06	21	0.08	0.08	30	0.08	0.07	21	-	-	-			
	Brood-rearing	3.97	2,68	0.02	0.35	0.15	28	0.45	0.13	23	0.47	0.19	20	-	-	-			
	Pooled	0.17	2,160	0.84	0.21	0.19	51	0.22	0.20	63	0.23	0.23	49	-	-	-	0.22	0.21	163

Table 18. ANOVA's to test for differences in prey procurement index (min out-of-canyon/prey item/day) among study locations for each year and nesting stage (*n* refers to the number of out-of-canyon trips).

					Construction			Recreation			Control			Blasting		
Year	Nesting Stage	*F*	df	*P*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
	Pre-incubation	-	-	-	415	80	2	-	-	-	-	-	-	-	-	-
1984	Incubation	0.66	1,27	0.42	309	166	19	259	142	10	-	-	-	-	-	-
	Brood-rearing	1.58	1,47	0.21	203	173	25	152	103	24	-	-	-	-	-	-
	Pooled	4.26	1,78	0.05	256	176	46	183	124	34	-	-	-	-	-	-
	Pre-incubation	1.71	2,19	0.20	220	167	6	306	116	8	190	107	8	-	-	-
1985	Incubation	1.18	3,51	0.32	220	113	18	303	175	17	240	183	10	307	156	10
	Brood-rearing	1.75	3,91	0.16	129	47	19	126	76	25	139	60	27	162	54	24
	Pooled	1.27	3,168	0.28	180	107	43	215	151	50	171	112	45	205	114	34
	Pre-incubation	2.75	2,30	0.08	282	146	11	508	388	12	517	170	10	-	-	-
1986	Incubation	4.68	2,47	0.01	443	202	20	282	166	14	273	188	16	-	-	-
	Brood-rearing	4.35	2,37	0.02	218	92	12	435	231	13	257	228	15	-	-	-
	Pooled	1.21	2,120	0.30	339	190	43	403	281	39	327	224	41	-	-	-
	Pre-incubation	1.88	2,12	0.19	332	115	2	191	119	8	377	252	5	-	-	-
1987	Incubation	1.67	2,39	0.20	332	140	7	217	138	20	253	152	15	-	-	-
	Brood-rearing	4.33	2,68	0.01	117	46	28	90	43	23	80	46	20	-	-	-
	Pooled	0.42	2,125	0.65	169	118	37	156	117	51	182	167	40	-	-	-

Table 19. ANOVA's to test for differences in prey procurement index (min out-of-canyon/prey item/day) among years for each nesting stage (*n* refers to the number of out-of-canyon trips per nesting stage and year).

	Pre-incubation			Incubation			Brood-rearing			Stages Pooled		
Year	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
1984	415	80	2	292	158	29	178	144	49	225	159	80
1985	240	133	22	265	156	55	140	62	95	193	124	172
1986	436	281	33	343	202	50	303	215	40	355	233	123
1987	272	186	15	249	146	42	98	47	71	168	134	128
Test statistic	F = 4.03 df = 3 and 68 P = 0.01			F = 2.89 df = 3 and 172 P = 0.03			F = 29.05 df = 3 and 251 P = 0.0001			F = 32.53 df = 3 and 499 P = 0.0001		

Prey Procurement in the BOPA over Time

When out-of-canyon time/pair/day was regressed on prey deliveries/pair/day for each year only for falcons nesting in the BOPA study locations, both slopes and intercepts of these regression lines were significantly different (ANCOVA, slope partial $F = 10.99$, df = 3 and 605, $P < 0.0001$; and intercept partial $F = 12.74$, df = 3 and 605, $P < 0.0001$) (Fig. 11). The shortest out-of-canyon time per delivered prey item was found for 1987 which did not differ from 1984 and 1986. The longest out-of-canyon time per delivered prey item was found in 1985, which did not differ from values calculated for 1986 (Tukey multiple comparison among slopes, $P = 0.05$). Procurement time of male and female falcons appeared to be compensatory as was suggested by a decrease in average successful procurement time for females during brood-rearing with increasing numbers of male-delivered prey items (Fig. 12).

In subsequent analyses with out-of-canyon time per pair/day only falcon pairs nesting in the BOPA were

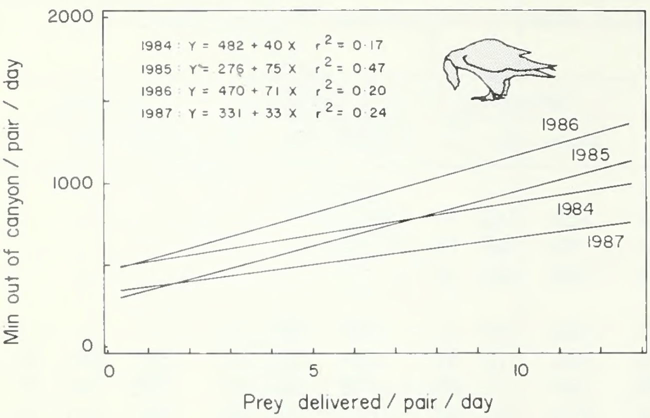


Fig.11 Out-of-canyon time/day of prairie falcon pairs regressed on prey delivered/pair/day for pairs nesting in the BOPA, 1984-1987.

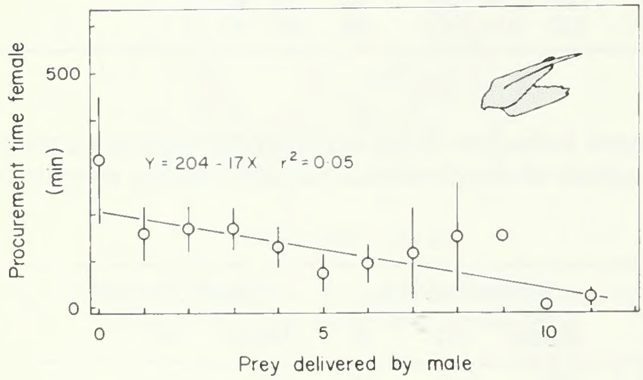


Fig.12 Time spent procuring prey by female prairie falcons regressed on number of prey items delivered by males, 1984-1987.

used for comparison among years. Out-of-canyon time per pair/day differed among years for each of the nesting stages (Table 20). During pre-incubation out-of-canyon time did not differ among 1984, 1985, and 1986, but was significantly lower in 1987 (Table 20; DMR, $P = 0.05$). Out-of-canyon time during incubation was also lower in 1987 than in the other years. The highest time was found for 1985, followed by 1984 and 1986. Likewise, out-of-canyon time during brood-rearing was lowest in 1987, followed by 1984, 1985 and 1986.

The number of out-of-canyon trips/pair/day was different among years for each of the nesting stages (Table 21). During pre-incubation the number of trips recorded for 1984, 1986 and 1987 was higher than in 1985 (Table 21; DMR, $P = 0.05$). The number of trips during incubation did not differ among 1984, 1986, and 1987, but was again lower in 1985. However, during brood-rearing the highest number of trips was recorded in 1987 and the lowest in 1985, with 1984 and 1986 in between (Table 21; DMR, $P = 0.05$).

When average number of prey delivered/pair during the brood-rearing stage was regressed on productivity, no significant differences were found among years (ANCOVA, slopes partial $F = 2.40$, df = 3 and 37, $P > 0.10$; intercepts partial $F = 2.85$, df = 3 and 37, $P > 0.10$). Therefore, the prey delivery data were pooled for all years (Fig. 13). The number of prey delivered per pair/day increased significantly with the number of young fledged per pair.

The average number of delivered prey items/pair/day during brood-rearing decreased significantly with progressively later incubation dates in 1985 and 1986. These relationships were not significant for 1984 and 1987. However, differences among years in slopes and intercepts of the regression lines proved not to be significant (ANCOVA, $F = 1.33$, df = 3 and 33, $P > 0.10$; and

Table 20. ANOVA's to test for differences in out-of-canyon time per pair/day for falcons nesting in the 3 BOPA study locations among years for each nesting stage (*n* refers to the number of out-of-canyon trips per nesting stage and year).

	Pre-incubation			Incubation			Brood-rearing		
Year	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
1984	99	72	12	85	73	206	79	67	470
1985	97	72	90	99	69	226	89	74	575
1986	97	100	281	76	74	370	102	104	308
1987	52	43	153	61	51	397	50	45	804
Test statistic	$F = 10.84$ df = 3 and 532 $P = 0.0001$			$F = 17.16$ df = 3 and 1195 $P = 0.0001$			$F = 59.66$ df = 3 and 2153 $P = 0.0001$		

Table 21. ANOVA's to test for differences in out-of-canyon trips per pair/day for falcons nesting in the 3 BOPA study locations among years for each nesting stage (*n* refers to the number of out-of-canyon trips per nesting stage and year).

	Pre-incubation			Incubation			Brood-rearing		
Year	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
1984	6.0	4.2	2	5.4	2.0	38	9.6	3.1	49
1985	3.4	1.2	26	3.4	1.5	65	8.1	3.3	71
1986	6.7	2.4	43	5.7	2.7	72	9.4	4.1	40
1987	7.7	4.0	20	5.5	2.3	72	11.3	3.6	71
Test statistic	F = 12.74			F = 15.51			F = 9.83		
	df = 3 and 87			df = 3 and 242			df = 3 and 227		
	P = 0.0001			P = 0.0001			P = 0.0001		

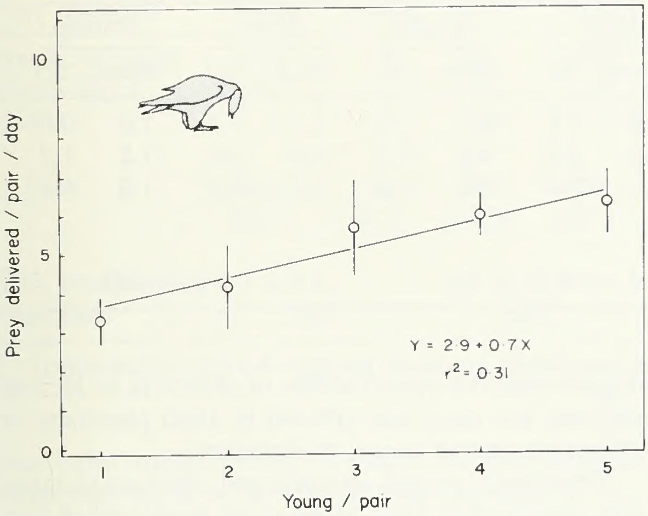


Fig.13 Average number of prey items delivered per pair/day regressed on productivity (young fledged/pair).

intercepts: F = 2.32, df = 3 and 33, $P > 0.10$). Thus, the data could be pooled for all years and showed an inverse relationship between the average number of prey delivered/pair/day and start of incubation (Fig. 14).

In 1986, 7 of 14 nesting attempts failed. Fifty percent of all failures at observed nesting territories from 1984-1987 occurred in 1986. In 1986, 7 of 10 pairs that nested late (i.e., after 15 April) failed. As mentioned above relatively low prey delivery rates (prey items delivered per pair/day) were typical of late nesting pairs and relatively high prey delivery rates characterized early nesting pairs. I compared prey delivery rates separately for early and late nesting falcons in 1986. Prey delivery rates were 38-51% higher for early nesters than for late nesters for each nesting stage (ANOVA's $0.05 < P < 0.001$, Table 22). In the BOPA prey delivery rates of early nesters in 1986 were significantly higher than those of early nesters in 1985 for the pre-incubation (ANOVA, F = 7.21, df = 1 and 33, P = 0.01) and incubation stages (ANOVA, F = 12.61, df = 1 and 98, P = 0.0006), but not for the brood-rearing stage (ANOVA, F = 1.99, df = 1 and 91, P = 0.16). In 1986 late nesting pairs showed relatively constant prey delivery rates during brood-rearing which were not associated with either the number of young fledged per pair or the age of the young (multiple linear regression, partial b = -0.48, P = 0.23, and partial b = 0.002, P = 0.96).

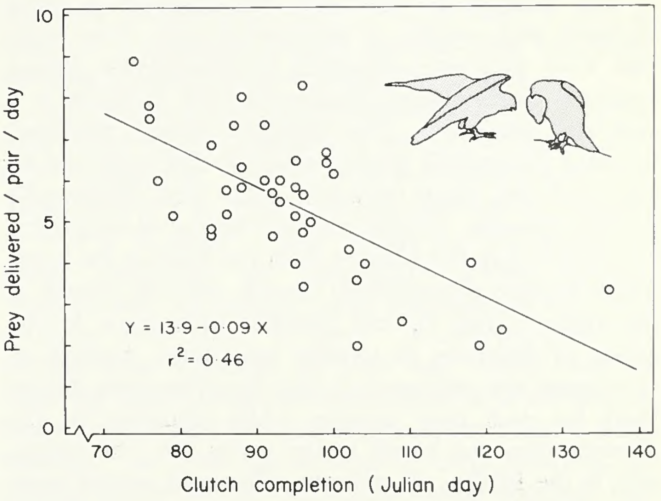


Fig.14 Average number of prey items delivered/day by prairie falcon pairs regressed on day of start incubation, 1984-1987.

Table 22. Numbers of prey items delivered, cached, and retrieved per day by prairie falcon pairs starting to incubate (A) before 15 April, and (B) after 15 April 1986.

A. Before 15 April (early nesters)

	Pre-incubation				Incubation				Brood-rearing			
	Male		Female		Male		Female		Male		Female	
Prey	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Delivered	2.4	1.2	0.0	0.0	1.7	1.1	0.1	0.3	3.9	1.8	1.2	1.3
Cached	0.0	0.0	0.3	0.5	0.3	0.6	0.3	0.5	0.3	0.6	1.0	1.0
Retrieved	0.1	0.3	0.2	0.7	0.4	0.7	0.3	0.6	0.5	1.0	0.9	1.1
Delivered by male and female	2.4 ± 1.3 (n = 9)				1.8 ± 1.1 (n = 35)				5.1 ± 2.1 (n = 22)			

B. After 15 April (late nesters)

	Pre-incubation				Incubation				Brood-rearing			
	Male		Female		Male		Female		Male		Female	
Prey	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Delivered	1.2	1.1	0.0	0.2	0.6	0.8	0.1	0.3	1.6	1.7	1.0	0.6
Cached	0.2	0.4	0.2	0.4	0.0	0.0	0.2	0.4	0.0	0.0	1.2	1.2
Retrieved	0.2	0.4	0.2	0.5	0.1	0.3	0.2	0.5	0.2	0.4	1.6	1.7
Delivered by male and female	1.2 ± 1.1 (n = 33)				0.7 ± 0.8 (n = 37)				2.6 ± 1.6 (n = 18)			

Diet

Prey brought to the aerie was classified as small mammal, bird, reptile, or unidentified prey. Prey items that were positively identified as Townsend's ground squirrels (*Spermophilus townsendii*) were assigned to a separate category. The category "small mammal" included Townsend's ground squirrels that could not be identified and small mammals other than Townsend's ground squirrels. Possible sources of bias in identifying prey items were the distance from the blind to the aerie, which became progressively shorter over the course of the study (Table 3), and possible differences in the ability of observers to identify prey items. Analysis of covariance was employed to test for differences among years for each prey category while adjusting for the distance from the blinds to the aeries (i.e., the covariate) in the BOPA. Significant differences among years were found in the categories Townsend's ground squirrel (ANCOVA, F = 12.21, df = 3 and 46, P < 0.0001), and small mammals (ANCOVA, F = 4.08, df = 3 and 46, P = 0.01), but not for unidentified prey items (ANCOVA, F = 0.31, df = 3 and 46, P = 0.81). This suggests that the overall ability of observers to identify prey may not have been affected by blind placement or differences among groups of observers.

Townsend's ground squirrels and other small mammals comprised at least 64.0% of all freshly killed prey items (n = 1759) delivered to the nesting territory in the BOPA (Table 23). Townsend's ground squirrels occurred most frequently in the prairie falcon's diet (37.1% of all delivered prey), followed by unidentified prey items (31.2%), small mammals (26.9%), birds (4.1%), and reptiles (0.7%). In 1985 the prey delivered by male and female falcons differed mainly because male falcons delivered a greater number of avian prey than females (X^2 = 9.43, df = 2, P = 0.009). For the other years the prey delivered by the sexes did not differ in species composition (1984: X^2 = 0.79, df = 2, P = 0.67; 1986: X^2 = 4.27, df = 2, P = 0.11; and 1987: X^2 = 0.39, df = 2, P = 0.82 (Table 24). Male falcons delivered a higher percent birds than females when all years were combined (X^2 = 5.93, df = 2, P = 0.05).

The diet of falcons nesting in the BOPA appeared to change from 1984-1987 (Fig. 15), although it should be emphasized that 23.4% to 42.0% of the delivered

Table 23. Diets of prairie falcons nesting in the BOPA, 1984-1987 (numbers in parentheses are percentages of the total number of prey items delivered to the nesting territories each year).

	Prey category											
Year	Unidentified		Small mammal		Ground squirrel		Bird		Reptile		Total	
1984	135	(42.0)	62	(19.2)	115	(35.7)	10	(3.1)	0	(0.0)	322	(100)
1985	156	(29.5)	176	(33.2)	162	(30.6)	29	(5.5)	9	(1.1)	529	(100)
1986	127	(36.6)	117	(33.7)	76	(21.9)	25	(7.2)	2	(0.6)	347	(100)
1987	131	(23.4)	119	(21.2)	299	(53.2)	11	(2.0)	1	(0.1)	561	(100)
Total	549	(31.2)	474	(26.9)	652	(37.1)	72	(4.1)	12	(0.7)	1759	(100)

Table 24. Prey delivered by male and female prairie falcons nesting in the BOPA, 1984-1987 (numbers in parentheses are percentages of the total number of prey items delivered by each sex).

	1984		1985		1986		1987		Total	
Prey category	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Small mammal*	143	34	252	86	165	28	305	113	865	261
Unidentified	110	25	108	48	100	27	93	38	411	138
Bird	7	3	33	2	25	2	8	4	73	11
Total	260 (89.7)	62 (19.3)	393 (74.3)	136 (25.7)	290 (83.6)	57 (16.4)	406 (72.4)	155 (27.6)	1349 (76.7)	410 (23.3)
Male and female combined	322		529		347		561		1759	

* Townsend's ground squirrel numbers combined with other small mammals.

prey items could not be identified. Small mammals comprised 19.2% of the diet in 1984, increased to 33.2 and 33.7% in 1985 and 1986, respectively, but declined to 21.2% in 1987 (Table 23). Percent Townsend's ground squirrel appeared to decrease from 35.7% in 1984 to 30.6% in 1985, and further down to 21.9% in 1986 (Table 23). In 1987, however, 53.2% of the prey items were Townsend's ground squirrels. The large percentage of unidentified prey items and the possibility that some small mammals were unidentified Townsend's ground squirrels, however, makes interpretation of these data somewhat speculative.

The diets of falcons nesting in the BOPA and those nesting in the blasting study location were compared only for 1985. The analyses were carried out with freshly delivered prey items as well as with freshly delivered prey and retrieved prey items combined. Higher numbers of birds and lower numbers of ground squirrels were delivered to nesting territories in the blasting study locations than to nesting territories in the BOPA (delivered prey: $X^2 = 29.68$, df = 3, $P < 0.0001$; delivered and retrieved prey: $X^2 = 34.15$, df = 3, $P < 0.0001$). Combining ground squirrels with the small mammal category did not change the results.

Differences in diet among the BOPA study locations were found for 1985, 1986, and 1987 ($X^2 = 24.13$, df = 6, $P < 0.0001$; $X^2 = 16.09$, df = 6, $P = 0.01$; and $X^2 = 31.39$, df = 6, $P < 0.0001$), but not for 1984 ($X^2 = 2.21$, df = 3, $P = 0.52$). These results did not change by either combining the Townsend's ground squirrel category with the category small mammals, by including retrieved prey items, or both. A difference in diet among study locations in 1985 was mainly due to relatively high numbers of birds delivered in the control study location and low numbers in the recreation study location. In 1986 the number of birds delivered to nesting territories in the control study location was again high compared to the construction and recreation study location, as was the number of Townsend's ground squirrels. Falcon pairs nesting in the construction and recreation study locations delivered more small mammals. In 1987 differences among study locations were

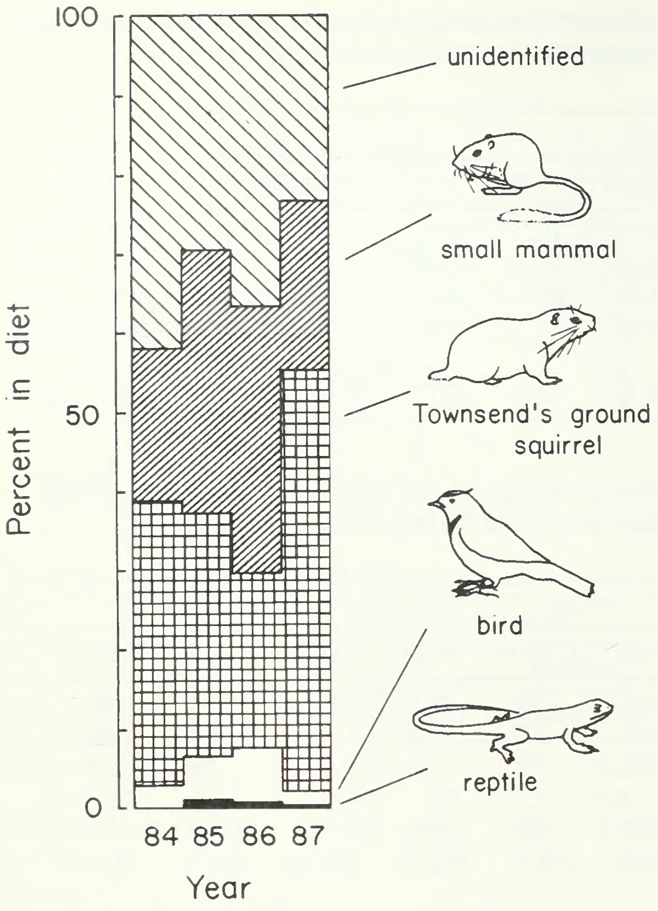


Fig.15 Diet of prairie falcons nesting in the BOPA, 1984-1987.

mainly related to high numbers of unidentified items delivered in the recreation study location, and relatively low numbers in the control study location. Pairs in the recreation study location delivered relatively high numbers of avian prey. Diet differences among study locations mentioned above were also observed when years were combined (X^2 = 43.08, df = 6, $P < 0.0001$). Relatively low numbers of avian prey were delivered in the construction study location and high numbers in the control study location. Also, in the construction study location a higher number of prey items could not be identified.

For each nesting pair of falcons, the percent Townsend's ground squirrels in the diet was calculated for the brood-rearing stage only and regressed on productivity. Productivity increased significantly with a higher percent of Townsend's ground squirrel in the diet (b = 0.08, t = 3.77, P = 0.0006; Fig. 16). Furthermore, the total time spent out-of-the canyon/pair averaged over the entire nesting cycle decreased significantly with an increasing proportion of Townsend's ground squirrels in the diet (r_T = -0.47, P = 0.002, n = 39 pairs).

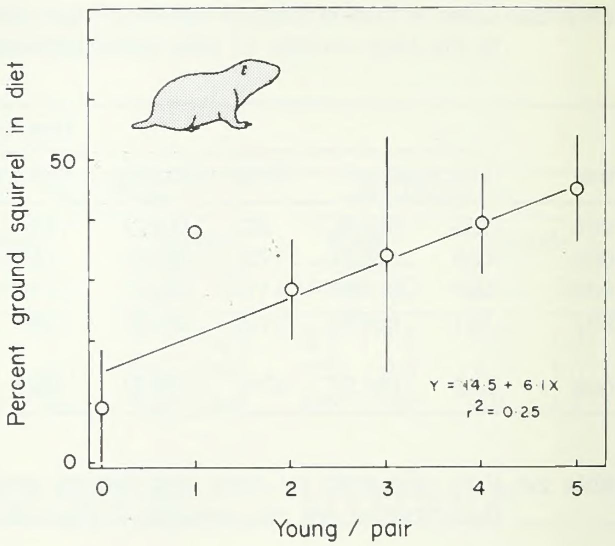


Fig.16 Percent Townsend's ground squirrel in the diet of prairie falcons nesting in the BOPA regressed on productivity, 1984-1987.

Relocation

The number of relocations/pair/day slowly increased during pre-incubation, decreased slowly after clutch completion, and increased again until about 1 week after hatch (Fig. 17). Significant differences were found among years, nesting stages, study locations, and nesting pairs (ANOVA, F = 17.48, df = 3 and 559, $P < 0.0001$; F = 85.18, df = 2 and 559, $P < 0.0001$; F = 9.68, df = 3 and 559, $P < 0.0001$; and F = 4.01, df = 45 and 559, $P < 0.0001$, respectively). The highest number of relocations was recorded in 1987 (32.5 ± 18.5 per day, n = 163) followed by 1984 and 1985 (24.6 ± 15.5 per day, n = 89, and 26.6 ± 15.0 per day, n = 207, respectively); the latter 2 years did not differ significantly (DMR, P = 0.05). In 1986 the number of relocations was similar to 1984 (22.6 ± 13.3 per day, n = 154). Prairie falcons in the recreation study location showed the highest number of relocations (30.2 ± 17.2 per day, n = 210), followed by the construction and control study locations (25.7 ± 14.2 per day, n = 200, and 25.8 ± 16.8 per day, n = 158, respectively), which both had more relocations than the blasting study location (20.5 ± 13.0 per day, n = 45) when all years were combined. Significant differences were also found in the average number of relocations/day among study locations for 1984 and 1985, but not for 1986 and 1987 (DMR, P = 0.05). In 1984, more relocations were recorded in the recreation than in the construction study location. However, in 1985 the number of relocations was similar in the construction and recreation study locations; both were higher than in the control and blasting study

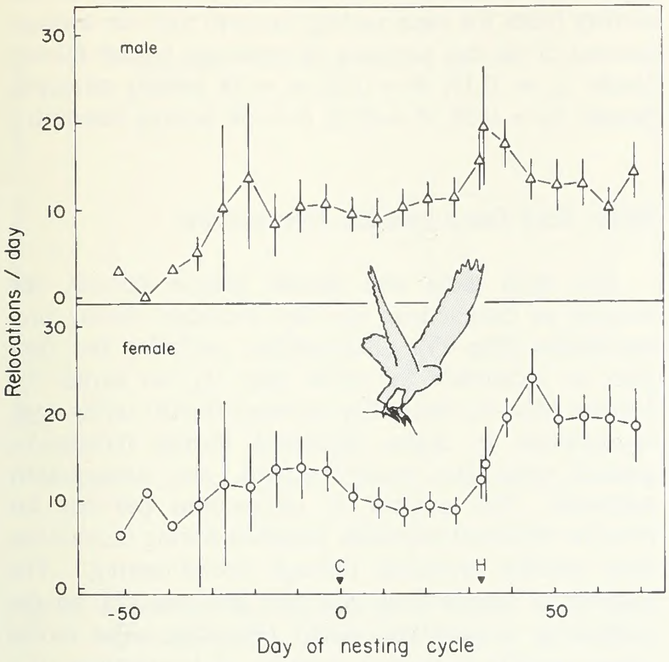


Fig.17 Number of relocations/day by male and female prairie falcons over the nesting cycle, 1984-1987.

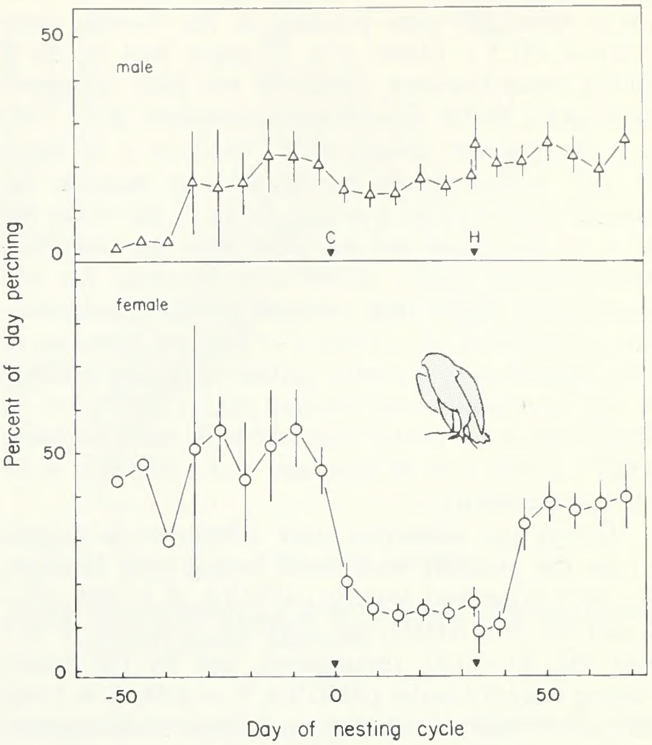


Fig.18 Percent of the day perching by male and female prairie falcons over the nesting cycle, 1984-1987.

locations. The same analyses were carried out for the number of relocations/pair/hour and relocations/pair/day with similar results. The average number of relocations per pair/day and the human activity index were not significantly correlated (r_T = 0.09, P = 0.51, n = 54 nesting attempts).

Perching

Perching and preening were collectively analyzed as 1 category (i.e., perching). Overall, females spent a higher proportion of the day perched than males (26.4 ± 20.2%, n = 613 days and 18.3 ± 12.7%, n = 613 days, respectively; t-test, t = -7.65, df = 1113, P < 0.0001). They perched more than males during pre-incubation and brood-rearing (ANOVA, F = 120.54, df = 1 and 180, P > 0.0001; and F = 31.67, df = 1 and 508, P < 0.0001, respectively), but not during incubation (F < 0.001, df = 1 and 532, P = 0.99) (Fig. 18). Males perched more per day during brood-rearing and pre-incubation (21.6 ± 13.4%, n = 255 days, and 19.8 ± 14.6%, n = 91 days, respectively) than during incubation (14.6 ± 10.1%, n = 267 days; DMR, P = 0.05). Females perched for a larger part of the day during pre-incubation (49.2 ± 19.5%, n = 91 days), less during brood-rearing (30.7 ± 19.4%, n = 255 days), and very little during incubation (14.6 ± 10.8%, n = 267 days). The rapid decline in perching during the latter part of the pre-incubation and early incubation stages coincides with an increase in incubation behavior by the female. Likewise, the increase in perching after hatch coincides with a decline in brooding of the young. Because temporal changes in perching were weak in males, but pronounced in females, perching per pair per day followed trends described for the female (Fig. 18).

Significant differences were found among years, study locations, nesting stages, nesting pairs, and sex in percent of day perching (ANOVA, F = 5.08, df = 3 and 1171, P = 0.0001; F = 8.95, df = 3 and 1171, P = 0.0001; F = 137.15, df = 2 and 1171, P = 0.0001; F = 3.30, df = 45 and 1171, P = 0.0001; and F = 78.32, df = 1 and 1171, P = 0.0001, respectively). Percent of the day perching in males differs among study locations in 1984, 1985, and 1987 (ANOVA, F = 4.58, df = 1 and 87, P = 0.03; ANOVA, F = 8.57, df = 3 and 203, P < 0.0001; and ANOVA, F = 4.49, df = 2 and 160, P = 0.01, respectively), but not in 1986 (ANOVA, F = 1.07, df = 2 and 151, P = 0.34). For females, differences in percent of day perching were only found in 1987 (ANOVA, F = 5.44, df = 2 and 160, P = 0.005); in all other years percent perching was similar among study locations (ANOVAs, P's > 0.15). Males spent more time perching in the recreation than the construction study location in 1984 (23.2 ± 14.8%, $n = 40$ days and 16.3 ± 10.2%, $n = 49$ days, respectively). In 1985, males spent less time perching in the blasting study location (12.5 ± 10.6%, $n = 45$ days) than in the 3 BOPA study locations, which did not differ (construction: 16.8 ± 10.0%, $n = 50$ days; recreation: 25.2 ± 18.3, $n = 56$ days; and control: 21.9 ± 13.5%, $n = 56$ days). In 1987 percent of the day perching by males in the control study location averaged 25.5 ± 14.1% of the day ($n = 49$ days), and did not differ from the recreation study location (22.5 ± 12.1%, $n = 63$ days), but was significantly higher than recorded for the construction study location (17.8 ± 11.0%; $n = 51$ days). Likewise, in 1987 females spent a smaller percent of the day perching in the construction study location (20.2 ± 17.5%, $n = 51$ days) than in the control and recreation study locations (30.3 ± 17.7%, $n = 49$ days, and 27.3 ± 17.8%, $n = 63$ days, respectively).

During the incubation stage differences in percent of the day perching were found among study locations for both males and females (ANOVA, $F = 5.86$, df = 3 and 263, $P = 0.0007$; and ANOVA, $F = 2.61$, df = 3 and 263, $P = 0.05$, respectively), and for the brood-rearing stage for males (ANOVA, $F = 8.24$, df = 3 and 251, $P < 0.0001$). During incubation, males spent a higher percent of the day perched in the recreation and control study locations (17.5 ± 10.9%, $n = 89$ days, and 15.7 ± 10.2%, $n = 60$ days, respectively) than in the blasting and construction study locations (12.9 ± 10.7%, $n = 21$ days, and 11.2 ± 8.0%, $n = 91$ days, respectively). Females, however, perched a higher percent of the day in the recreation, control and construction study locations (16.5 ± 10.9%, $n = 80$ days, 14.5 ± 9.9%, $n = 66$ days, and 13.4 ± 10.6%, $n = 91$ days, respectively) than in the blasting study location (11.7 ± 12.2%, $n = 21$ days). During brood-rearing males perched a smaller percent of the day in the blasting study location than in either the recreation, control, or construction study locations (12.2 ± 10.7%, $n = 24$ days versus 25.0 ± 13.6%, $n = 85$ days, 24.5 ± 15.1%, $n = 62$ days, and 18.7 ± 10.4%, $n = 84$ days, respectively). When all years were combined and a comparison in percent of the day perching among study locations was made for males and females separately, significant differences were only found for males. Overall, males perched more in the recreation and control study locations (25.7 ± 20.6%, $n = 200$ days, and 20.2 ± 13.8%, $n = 158$ days, respectively) than in the construction study location (15.6 ± 11.0%, $n = 200$ days) and even less in the blasting study location (12.5 ± 10.6%, $n = 45$ days).

Although differences were found for both males and females in percent of the day perching among study locations for some years and nesting stages, no significant correlation was found between the human activity index for each nesting attempt and the average percent of the day perching by male and female falcons (male: $r_T = -0.11$, $P = 0.23$, $n = 54$ nesting attempts; female: $r_T = 0.03$, $P = 0.70$, $n = 54$ nesting attempts).

Inter- and Intra-specific Interactions

For both male and female prairie falcons, the number of interactions per day increased during pre-incubation (Fig. 19). Interactions peaked a few days prior to incubation for males (day -3), but earlier for females (day -9), when they probably started laying eggs. Interactions in males increased during incubation, peaked when the young hatched, and subsequently declined. The number of interactions per day for females remained relatively constant during incubation, then steadily increased through brood-rearing. The number of interactions per pair per day can be described by a quadratic model (Fig. 20). The model shows steadily increasing numbers of interactions of a pair through pre-incubation and most of the incubation stage, with a peak during the last week of the incubation stage followed by a decline.

The diurnal frequency distribution of interactions showed a bimodal pattern for both males and females,

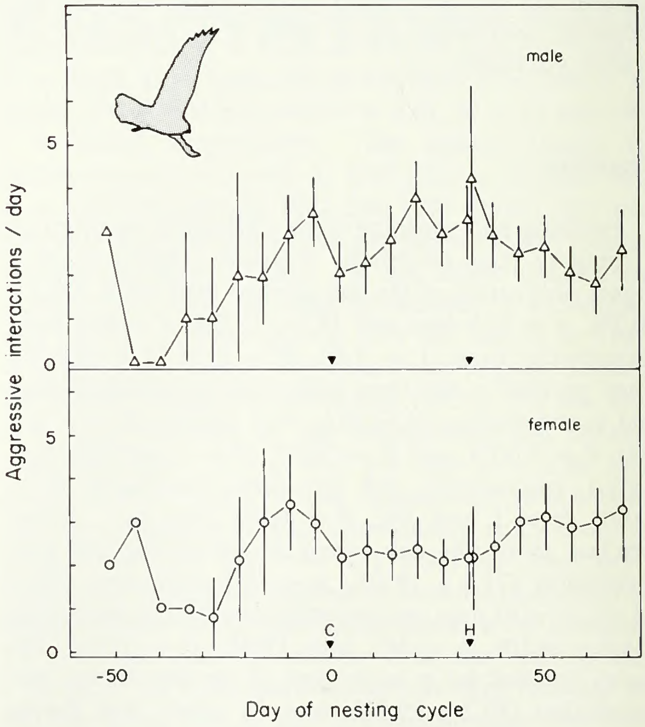


Fig.19 Number of interactions/day by male and female prairie falcons over the nesting cycle, 1984-1987.

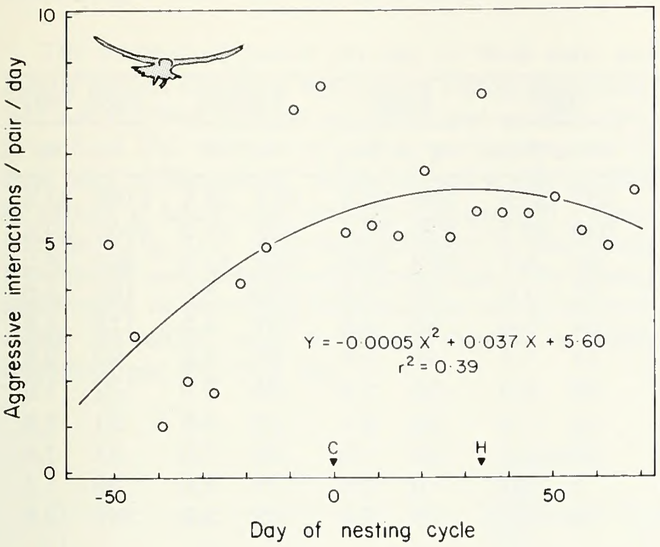


Fig.20 Number of interactions/day of prairie falcon pairs regressed on day of the nesting cycle, 1984-1987.

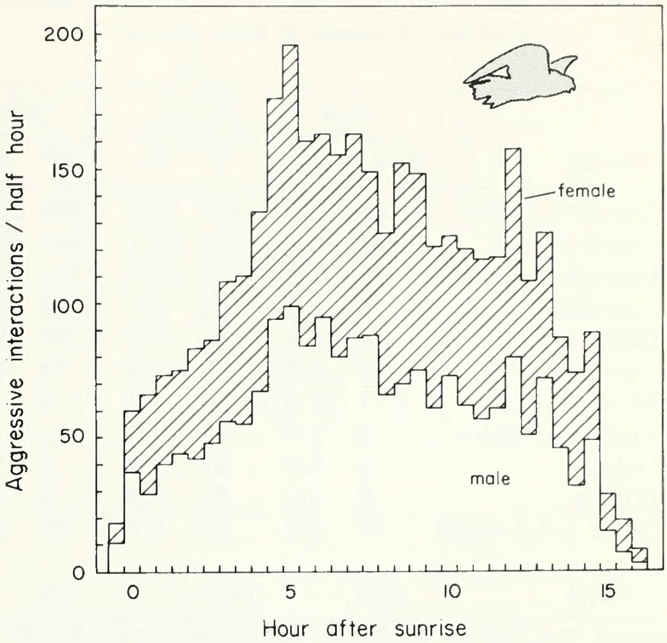


Fig.21 Diurnal distribution of interactions of male and female prairie falcons, 1984-1987.

with the highest level in mid-morning (4.5-5 hours after sunrise) (Fig. 21). Males and females showed a similar pattern in interactions during the day (X^2 = 25.57, df = 34, P = 0.85).

Interactions between prairie falcons and intruders in the nesting territory (n = 3697) were divided into 4 levels of decreasing aggression (Appendix 2): (1) attack (59.0%), (2) vocal (31.0%), (3) non-aggressive (6.0%), and (4) defensive (4.0%). The level of aggression differed among years (X^2 = 202.85, df = 9, P < 0.001), with the highest levels observed in 1984 and 1987 (73.4% and 65.4% of the interactions were attacks) (Table 25). Species most frequently attacked in decreasing order of frequency, were common ravens (*Corvus corax*), other prairie falcons, red-tailed hawks, unknown antagonists, and golden eagles (*Aquila chrysaetos*) (88% of all interactions, Table 26). Northern harriers (*Circus cyaneus*), American kestrels (*Falco sparverius*), human visitors, and bobcat (*Lynx rufus*) were each involved in fewer than 2% of all interactions. Males attacked other prairie falcons and American kestrels more frequently than females, but bobcats were more frequently attacked by females (X^2 = 53.50, df = 12, P < 0.0001; Table 26). The average number of interactions between prairie falcons and other species was directly related to the average nesting density of these species in the BOPA recorded from 1975-1978 (U.S. Dep. Inter. 1979, Table 14) (r_T = 0.56, P = 0.04).

Table 25. Interactions between nesting prairie falcons and intruders by year, categorized according to level of aggression (n denotes number of interactions).

	1984		1985		1986		1987		1984-1987	
Aggression level	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Attack	361	73.4	743	51.9	427	54.8	651	65.4	2182	59.0
Vocal	85	17.3	542	37.9	257	33.0	263	26.5	1147	31.0
Non-aggressive	34	6.9	83	5.8	70	9.0	35	3.5	222	6.0
Defensive	12	2.4	63	4.4	25	3.2	46	4.6	146	4.0
Total	492	100.0	1431	100.0	779	100.0	995	100.0	3697	100.0

Table 26. Interactions between nesting prairie falcons and species of intruder by year and sex, 1984-1987 (*n* denotes numbers of interactions).

	1984		1985		1986		1987		Male		Female		1984-1987	
Intruder	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Common Raven	165	33.5	386	27.0	308	39.5	337	33.9	589	30.4	607	34.5	1196	32.3
Prairie Falcon	197	40.0	330	23.1	247	31.7	329	33.1	628	32.4	475	27.0	1103	29.8
Red-tailed Hawk	39	7.9	359	25.1	101	13.0	91	9.1	322	16.6	268	15.2	590	16.0
Unknown	16	3.3	101	7.1	29	3.7	40	4.0	84	4.3	102	5.8	186	5.0
Golden Eagle	29	5.9	64	4.5	30	3.8	54	5.4	90	4.6	87	4.9	177	4.8
Turkey Vulture	8	1.6	60	4.2	13	1.7	11	1.1	41	2.1	51	2.9	92	2.5
Northern Harrier	7	1.4	30	2.1	2	0.3	33	3.3	36	1.9	36	2.0	72	1.9
American Kestrel	8	1.6	14	1.0	15	1.9	14	1.4	40	2.1	11	0.6	51	1.4
Human	2	0.4	27	1.9	2	0.3	20	2.0	23	1.2	28	1.6	51	1.4
Bobcat	2	0.4	21	1.5	9	1.1	7	0.7	8	0.4	31	1.8	39	1.1
Other (<1% each)	19	3.8	39	2.7	23	2.9	59	5.9	75	3.9	65	3.6	140	3.8
Total	492		1431		779		995		1936		1761		3697	

Overall, the number of interactions was similar for male and female falcons (t-test, $t = 1.36$, df = 1206, $P = 0.17$). The following results are based on the number of interactions per pair/day for all categories of aggression combined. The same analyses were carried out with the number of interactions/pair/hour with similar results. Significant differences were found among years, study locations, nesting stages, and nesting pairs (ANOVA, $F = 6.53$, df = 3 and 559, $P = 0.0002$; $F = 14.38$, df = 3 and 559, $P = 0.0001$; $F = 2.59$, df = 2 and 559, $P = 0.07$; and $F = 4.72$, df = 45 and 559, $P = 0.0001$, respectively). The highest number of interactions per day were found for 1985 and 1987 (6.5 ± 5.9 per day, $n = 207$, and 6.3 ± 4.3 per day, $n = 163$, respectively), followed by 1984 and 1986 (5.1 ± 4.2 per day, $n = 89$, and 4.8 ± 4.5 per day, $n = 154$, respectively; DMR, $P = 0.05$). When interaction data were analyzed for each year separately to test for differences among study locations, significant differences were found for 1984 and 1985 (ANOVA, $F = 16.88$, df = 1 and 87, $P < 0.0001$; and ANOVA, $F = 7.90$, df = 3 and 203, $P < 0.0001$, respectively), but not for 1986 and 1987 (ANOVA, $F = 0.37$, df = 2 and 151, $P = 0.69$; and ANOVA, $F = 0.24$, df = 2 and 160, $P = 0.78$, respectively). In 1984 interactions/pair were considerably higher in the recreation than the construction study location (7.0 ± 3.0 per day, $n = 40$, and 3.6 ± 3.3 per day, $n = 40$, respectively; DMR, $P = 0.05$). In 1985 the number of interactions/pair was lower in the blasting study location (3.1 ± 2.4 per day; 6 and 1987 (ANOVA, $F = 0.37$, df = 2 and 151, $P = 0.69$; and ANOVA, $F = 0.24$, df = 2 and 160, $P = 0.78$, respectively). In 1984 interactions/pair were considerably higher in the recreation than the construction study location (7.0 ± 3.0 per day, $n = 40$, and 3.6 ± 3.3 per day, $n = 40$, respectively; DMR, $P = 0.05$). In 1985 the number of interactions/pair was lower in the blasting study location (3.1 ± 2.4 per day; $n = 45$) than in each of the 3 BOPA study locations which all showed similar interaction levels (construction: 6.7 ± 4.4 per day, $n = 50$; recreation: 8.4 ± 7.1 per day, $n = 56$; and control: 7.1 ± 6.6 per day, $n = 56$; DMR, $P = 0.05$).

For all years combined, the frequency of interactions was significantly lower in the blasting study location (3.1 ± 2.4 per day, $n = 45$) than in the 3 BOPA study locations (construction: 5.4 ± 4.6 per day, $n = 200$; recreation: 6.6 ± 5.4 per day, $n = 210$; and control: 6.1 ± 5.1 per day, $n = 158$, respectively; DMR, $P = 0.05$). Because nesting stage also affects interaction levels, comparisons were made with numbers of interactions/day among study locations for each nesting stage. Differences were found among study locations in the incubation and brood-rearing stages (ANOVA, $F = 4.50$, df = 3 and 263, $P = 0.004$; and ANOVA, $F = 4.17$, df = 3 and 251, $P = 0.006$, respectively), but not for the pre-incubation stage (ANOVA, $F = 0.13$, df = 2 and 88, $P = 0.88$). For the incubation and brood-rearing stages the 3 BOPA study locations did not differ in number of interactions, but all showed higher numbers of interactions than the blasting study location (DMR, $P = 0.05$).

The average number of interactions per nesting pair calculated over the entire year did not show a significant correlation with the human activity index calculated for each nesting attempt ($r_T = -0.08$, $P = 0.56$, $n = 54$ nesting attempts).

Patrolling

The number of patrols per day for both male and female falcons combined was highest during pre-incubation and declined through incubation and brood-rearing (Fig. 22). The number of patrols per day peaked 10 days prior to incubation. Males showed a high number of patrols at hatch while females demonstrated a sharp decrease (Fig. 22). Patrolling declined in both sexes towards the end of the brood-rearing stage. The diurnal distribution of patrolling frequency did not show clear trends for either male or female falcons, or when calculated per pair (Fig. 23).

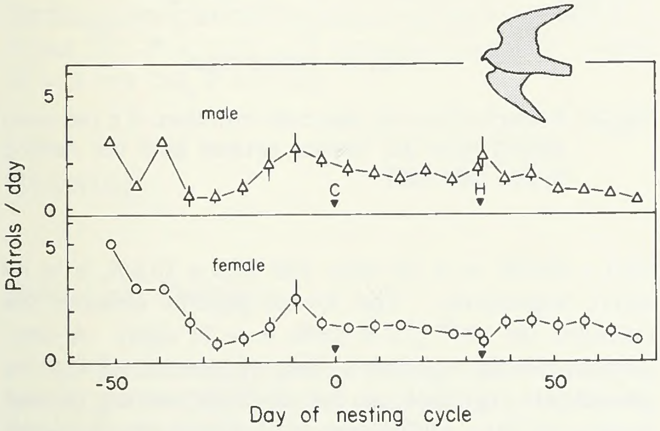


Fig.22 Number of patrols/day by male and female prairie falcons over the nesting cycle, 1984-1987.

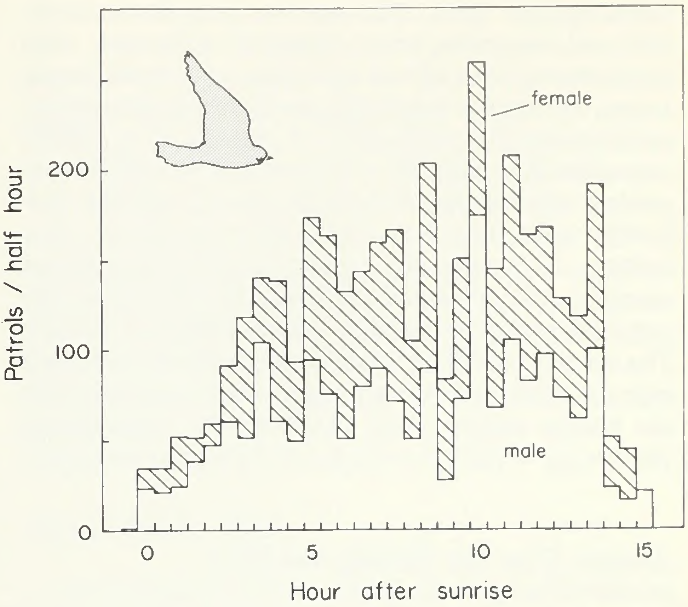


Fig.23 Diurnal distribution of patrols of male and female prairie falcons, 1984-1987.

Differences in patrolling frequency per pair/day were found among years, study locations, nesting stages, and nesting pairs (ANOVA, $F = 57.95$, df = 3 and 559, $P = 0.0001$; $F = 9.76$, df = 3 and 559, $P = 0.0001$; $F = 14.89$, df = 2 and 559, $P = 0.0001$; and $F = 2.28$, df = 45 and 559, $P = 0.0001$, respectively). In 1984 patrolling frequency (5.9 ± 4.3 patrols/day, $n = 89$) was higher than in 1985 and 1986 (2.3 ± 2.8 patrols/day, $n = 207$; and 2.8 ± 3.0 patrols/day, $n = 154$, respectively). The lowest patrolling frequency was recorded in 1987 (1.3 ± 2.1 patrols/day, $n = 163$) (DMR, $P = 0.05$). Most patrolling occurred during the pre-incubation stage (3.7 ± 3.6 patrols/day, $n = 91$), followed by the incubation and brood-rearing stages, which were similar in patrolling frequency (2.7 ± 2.9 patrols/day, $n = 267$; and 2.3 ± 3.4 patrols/day, $n = 255$, respectively) (DMR, $P = 0.05$). When patrolling data were analyzed for each year separately to test for differences among study locations, differences were found for 1985 and 1986 (ANOVA, $F = 8.62$, df = 3 and 203, $P = 0.0001$; and incubation stage (3.7 ± 3.6 patrols/day, $n = 91$), followed by the incubation and brood-rearing stages, which were similar in patrolling frequency (2.7 ± 2.9 patrols/day, $n = 267$; and 2.3 ± 3.4 patrols/day, $n = 255$, respectively) (DMR, $P = 0.05$). When patrolling data were analyzed for each year separately to test for differences among study locations, differences were found for 1985 and 1986 (ANOVA, $F = 8.62$, df = 3 and 203, $P = 0.0001$; and $F = 4.36$, df = 2 and 151, $P = 0.01$, respectively), but not for 1984 and 1987 (ANOVA, $F = < 0.01$, df = 1 and 87, $P = 0.95$; and $F = 2.01$, df = 2 and 160, $P = 0.13$, respectively). In 1985 falcons patrolled more in the construction and recreation study locations (3.5 ± 3.2 patrols/day, $n = 50$; and 2.6 ± 2.8 patrols/day, $n = 56$, respectively), than in the control study location (2.0 ± 2.6 patrols/day, $n = 56$). The patrolling frequency was lowest in the blasting study location (0.8 ± 1.5 patrols/day, $n = 45$) (DMR, $P = 0.05$). In 1986 falcons again patrolled more in the construction and recreation study locations (3.4 ± 3.6 patrols/day, $n = 50$; and 3.2 ± 2.4 patrols/day, $n = 51$, respectively) than in the control study location (1.8 ± 2.8 patrols/day, $n = 53$) (DMR, $P = 0.05$). When all years were combined for each study location the patrolling frequency was highest in the construction and recreation study locations (3.4 ± 3.6 patrols/day, $n = 200$; and 3.1 ± 3.3 patrols/day, $n = 210$, respectively), followed by the control study location (1.6 ± 2.6 patrols/day, $n = 158$), and the blasting study location which showed the lowest patrolling frequency (0.8 ± 1.5 patrols/day, $n = 45$) (DMR, $P = 0.05$). Patrolling frequency in the control study location was similar among years for each nesting stage, a remarkable constancy over time. However, for both the construction and recreation study locations, differences were found among years for the incubation and brood-rearing stages, but not for the pre-incubation stage (incubation: construction $F = 6.42$, df = 3 and 87, $P = 0.0006$, recreation $F = 5.21$, df = 3 and 85, $P = 0.02$; brood-rearing: construction $F = 25.21$, df = 3 and 80, $P = 0.0001$, recreation $F = 11.16$, df = 3 and 81, $P = 0.0001$). Generally, the highest patrolling frequencies were found for 1984 and the lowest for 1987, with 1985 and 1986 having intermediate values (DMR, $P = 0.05$). The average patrolling frequency per pair/day calculated over the entire year was not significantly correlated with the human activity index calculated for each nesting attempt ($r_T = 0.07$, $P = 0.41$, $n = 54$ nesting attempts).

Absence from the Nesting Territory

Percent absence per pair/day from the nesting territory was calculated as the percent of time per day both sexes were away from the nesting territory simultaneously. The proportion of the day a pair was absent from the nesting territory was relatively high 4 weeks prior to the incubation stage (21.8 ± 11.5%, $n = 4$ days), but decreased rapidly through the pre-incubation stage and averaged 6.9 ± 8.7% ($n = 35$ days) 3 days prior to start of incubation. The percent of the day a pair was absent remained at about the same low level throughout incubation (2.2 ± 3.9%, $n = 262$ days), but rapidly increased during brood-rearing from only 1.1 ± 1.9% ($n = 14$ days) just after hatch to 27.3 ± 21.1% ($n = 27$ days) when the young were 35 days old (Fig. 24).

Differences in percent of the day absent/pair were found among years and nesting stages, but not among study locations or nesting pairs (ANOVA, $F = 6.90$, df = 3 and 548, $P = 0.0001$; $F = 103.55$, df = 2 and 548, $P = 0.0001$; $F = 2.13$, df = 3 and 548, $P = 0.095$; and $F = 1.15$, df = 44 and 548, $P = 0.23$, respectively). For 1987 a significantly lower percent absence (5.5 ± 8.5%; $n = 163$ days) was found than for other years (1984: 10.7 ± 13.9%, $n = 89$ days; 1985: 14.3 ± 9.3%, $n = 207$ days; and 1986: 12.5 ± 19.9%, $n = 143$ days, respectively; DMR, $P = 0.05$). For each nesting stage differences were found among years (pre-incubation: $F = 3.16$, df = 3 and 85, $P = 0.03$; incubation: $F = 9.32$, df = 3 and 258, $P = 0.0001$; and brood-rearing: $F = 10.00$, df = 30 and 246, $P = 0.0001$), but a consistent pattern was not evident. During brood-rearing, which is the most stressful part of the nesting cycle as was found for example in peregrine falcons (Hunter et al. 1988) and European sparrowhawks (Newton 1986), adult falcons showed the highest percent absence of the day in 1985, 1986, and 1984 (26.5 ± 23.2%, $n = 95$ days, 26.1 ± 28.2%, $n = 35$ days, and 15.9 ± 16.8%, $n = 49$ days) respectively. The lowest percent absence was recorded for 1987 (5.2 ± 3.6%, $n = 71$ days). A comparison among regression lines of percent of the day absent/pair regressed on day of brood-rearing showed similar results. Differences were found among slopes and intercepts (ANCOVA: slopes partial $F = 8.17$, df = 3 and 242, $P < 0.0001$); intercepts partial $F = 4.42$, df = 3 and 242, $P < 0.01$). The slopes of the regression lines for 1984 and 1987 were similar, but were smaller than for 1985, which again was smaller than for 1986 (Tukey multiple comparison of slopes, $P = 0.05$). The intercepts of the regression lines for 1985 and 1986 were much higher than for 1984 and 1987. Thus, percent of the day absent/pair during brood-rearing was higher in 1986 than in 1985, which was again higher than in 1984 and 1987.

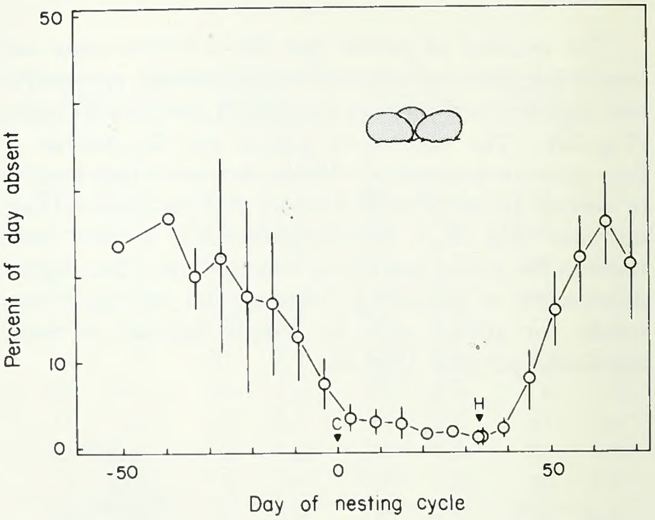


Fig.24 Percent of the day that both members of a pair were absent from the nesting territory over the nesting cycle, 1984-1987.

Differences were not observed in percent of the day absent/pair among study locations for each of the years separately (ANOVA's, 1984: $F = 0.14$, df = 1 and 87, $P = 0.70$; 1985: $F = 1.36$, df = 3 and 203, $P = 0.25$; 1986: $F = 2.12$, df = 2 and 153, $P = 0.12$; and 1987: $F = 1.04$, df = 2 and 165, $P = 0.35$). Also, the pre-incubation and incubation stages did not show differences in percent of the day absent/pair among study locations (ANOVA, $F = 0.42$, df = 2 and 86, $P = 0.66$; and $F = 1.25$, df = 3 and 258, $P = 0.29$, respectively). During brood-rearing adult falcons were absent for a larger proportion of the day in the blasting study location (29.9 ± 9.3%, $n = 24$ days) than in the 3 BOPA study locations, which were similar in percent absence/pair/day (construction: 15.9 ± 18.0%, $n = 84$

days; recreation: 18.5 ± 20.5%, $n = 85$ days; and control: 20.5 ± 25.7%, $n = 57$ days; ANOVA, $F = 2.62$, df = 3 and 246, $P = 0.05$). When all years and stages were combined, falcon pairs in the blasting study location were again absent for a higher percent of the day (18.1 ± 21.5%, $n = 45$ days) than falcons nesting in each of the 3 BOPA study locations (construction: 9.2 ± 14.1%, $n = 200$ days; recreation: 10.4 ± 16.6%, $n = 210$ days; and control: 11.8 ± 19.3%, $n = 146$ days), which did not differ in percent absence/pair/day ($F = 2.43$, df = 3 and 597, $P = 0.06$; DMR, $P = 0.05$). Percent of the day absent/pair was regressed on day of brood-rearing to test for differences among the study locations. Differences among the regression lines for each of the study locations were found for neither the slopes nor the intercepts (ANCOVA, slopes partial $F = 0.38$, df = 3 and 242, $P > 0.10$; and intercepts partial $F = 0.62$, df = 3 and 242, $P > 0.10$).

Blasting

Behavioral Reaction

The behavioral reaction to blasting was evaluated by type of pre-blasting behavior compared to post-blasting behavior (Table 27). Common pre-blast behaviors included perching ($n = 123$), incubating ($n = 90$), brooding ($n = 22$), flight-in-canyon ($n = 9$), and preening ($n = 5$). Perched falcons ($n = 100$) exposed to experimental blasting usually reacted by a short flight in the canyon ($n = 79$), followed by perching, or remaining perched after the blast ($n = 21$). Falcons perched ($n = 23$) in the construction study location exposed to blasting, usually remained perched ($n = 17$), made a short flight in the canyon ($n = 4$), or directed aggression towards neighboring raven pairs ($n = 2$). Incubating falcons exposed to experimental blasting ($n = 61$) continued incubating ($n = 26$), briefly sat up and continued incubating ($n = 12$); or made a short flight in the canyon, and returned to the aerie and resumed incubation (3.4 ± 3.7 min, range = 1.0-15.0 min, $n = 22$). In 1 instance an incubating falcon flew out of the aerie and out-of-view. The falcon was not observed to fly back to the aerie, but was found incubating 30 min after the blast. In the construction study location, however, incubating falcons ($n = 29$) reacted only in 2 cases by perching at the aerie entrance; both resumed incubation within 1 min. Brooding falcons usually continued brooding in 11 of 15, and 7 of 7 instances in the blasting and the construction study locations, respectively). In 2 instances brooding falcons flew out of the aerie; they returned within minutes (3.5 ± 0.7 min) and resumed brooding. Flying falcons ($n = 9$) continued circling ($n = 4$), disappeared out-of-view ($n = 3$), perched ($n = 1$), and in 1 instance reacted aggressively towards an American kestrel. Preening falcons ($n = 5$) usually continued preening ($n = 3$), or perched ($n = 1$); in 1 instance a bird flew off. Falcons were feeding in 3 instances when blasting took place; they either discontinued feeding, flew off and circled in the canyon, or flew off and disappeared out of view. In 2 cases a female falcon in the construction study location was inspecting a prospective aerie at the time of blasting; she did not visibly react in 1 instance, and in the other case the falcon flew off and perched.

Readjustment Time

In 4 instances falcons flying ($n = 3$), or incubating ($n = 1$) left the nesting territory after a blast. The incubating falcon was observed in the aerie 30 min after the blast. However, I was not able to determine when this falcon returned. The other falcons did not return within 30 min after the blast. I excluded these 4 observations from calculations of readjustment time. Only observations on birds known to be in the nesting territory at the time of the blast were included in the analyses. Readjustment time did not differ among nesting pairs exposed to either experimental or construction blasting (Kruskal-Wallis test, $X^2 = 7.44$, df = 3, $P = 0.05$ and $X^2 = 0.99$, df = 3, $P = 0.80$, respectively). No differences were found in readjustment time between male and female falcons exposed to experimental blasting (Wilcoxon 2-sample test, $z = -0.60$, $P = 0.54$), or construction blasting (Wilcoxon 2-sample test, $z = 1.70$, $P = 0.09$). Falcons exposed to experimental blasting showed longer readjustment times ($\bar{x} = 1.8 \pm 0.2$ (SE) min, $n = 183$) than falcons exposed to construction blasting (0.5 ± 0.2 (SE) min, $n = 67$) for all nesting stages combined (Wilcoxon 2-sample test, $z = -6.46$, $P < 0.0001$) as well as for both the incubation and brood-rearing stages separately (Wilcoxon 2-sample test, $z = -5.08$, $P < 0.0001$; and $z = -2.95$, $P = 0.003$, respectively). In the construction study location, the response to blasting was similar between nesting stages for male and female falcons ($X^2 = 0.61$, df = 2, $P = 0.72$). However, in the blasting study location the response rate was higher than expected for males during incubation, but lower than expected during brood-rearing; for females the opposite situation was found ($X^2 = 10.29$, df = 1, $P = 0.001$). Response rates to blasting were similar for male and female falcons in both the experimental and the construction study location when nesting stages were combined (Fisher exact test, $P = 0.45$, and $P = 0.10$, respectively).

Table 27. Behaviors of prairie falcons before and after experimental and construction blasting.

Behaviors	No. observations			Behaviors	No. observations		
before blasting	Experimental	Construction	Total	after blasting	Experimental	Construction	Total
Perching	100	23	123	Perching	21	17	38
				Flight-in-canyon	79	4	83
				Aggression	0	2	2
Incubating	61	29	90	Incubating	26	27	53
				Perching	12	2	14
				Flight-in-canyon	23	0	23
Brooding	15	7	22	Brooding	11	7	18
				Perching	2	0	2
				Flight-in-canyon	2	0	2
Flight-in-canyon	5	4	9	Flight-in-canyon	2	2	4
				Perching	1	0	1
				Aggression	0	1	1
				Out-of-view	2	0	2
				Out-of-canyon	0	1	1
Preening	2	3	5	Preening	0	3	3
				Perching	1	0	1
				Flight-in-canyon	1	0	1
Feeding adult	3	0	3	Feeding adult	0	0	0
				Perching	1	0	1
				Flight-in-canyon	1	0	1
				Out-of-canyon	1	0	1
Nest visit	0	2	2	Nest visit	0	1	1
				Flight-in-canyon	0	1	1
Total	186	68	254	Total	186	68	254

Habituation --- Habituation is defined as the waning of a response to a repeated activity (Marler and Hamilton 1966). Differences were found in readjustment time among 6-day intervals of the nesting cycle in the experimental study location (Kruskal-Wallis test, X^2 = 24.49, df = 11, *P* = 0.01), but readjustment time and day of the nesting cycle were not significantly correlated (r_T = -0.01, *P* = 0.80, *n* = 183). Likewise, readjustment time and day of the nesting cycle were not correlated for falcons exposed to construction blasting (r_T = -0.07, *P* = 0.48, *n* = 67). Thus, there was no evidence of habituation to either experimental or construction blasting. On a daily basis a marginal difference was found among the 3 sequential experimental blasts (X^2 = 6.09, df = 2, *P* = 0.05). Falcons showed long, but similar readjustment times, to the 1st and 2nd blast, but a significantly shorter readjustment time to the 3rd blast (nonparametric multiple comparison, *P* = 0.05). Readjustment time of falcons in the experimental study location decreased with increasing daily precipitation during brood-rearing, but not during incubation (r_T = -0.22, *P* = 0.01, *n* = 83 and r_T = -0.10, *P* = 0.22, *n* = 100, respectively). Other weather variables (average daily temperature, total solar radiation, and wind speed) were not significantly correlated with readjustment time (*P*'s > 0.10).

Behavioral Repertoire --- Differences were found for some behaviors expressed in percentages when the overall behavioral repertoire of prairie falcons exposed to experimental blasting was compared with the behavioral repertoire of falcons nesting in the control study location in 1985 (Table 28). Males and females in the blasting study location were out of view for longer periods than falcons in the control study location (ANOVA, incubation: $F = 4.53$, df = 1 and 39, $P = 0.03$, and $F = 10.42$, df = 1 and 39, $P < 0.01$, respectively). Such differences, however, were not found for the brood-rearing stage. This may be related to shorter perching times for males in the blasting study location compared to the control study location (ANOVA, $F = 4.96$, df = 1 and 49, $P = 0.03$). During brood-rearing differences between the falcons nesting in the control and blasting study locations were found for the percent of time perching, preening, and flying-in-the canyon by males. This may be due in part to the fact that prairie falcons were more difficult to follow in the blasting than in the control study location, because of the configuration of the cliffs in the former area. Similar differences, although not as pronounced, were found for the females. Overall, the behavioral repertoire between falcons in the blasting and control study locations did not reveal substantial differences, which was supported by low ASCC values ("best" discriminant models $0.11 < \text{ASCC} < 0.36$). Some differences in behaviors between the 2 groups of nesting falcons could also be observed when frequencies at which behaviors occurred were compared (Table 29). During incubation males in the blasting study location patrolled less frequently and engaged in fewer interactions than males in the control study location (ANOVA, $F = 4.41$, df = 1 and 30, $P = 0.04$, and $F = 5.80$, df = 1 and 39, $P = 0.02$, respectively). Differences were not found for the females. During brood-rearing the frequency of interactions was lower for both males and females in the blasting study location than for falcons nesting in the control study location (ANOVA, $F = 6.55$, df = 1 and 49, $P = 0.01$, and $F = 4.64$, df = 1 and 49, $P = 0.03$, respectively). These differences were relatively minor, as indicated by low ASCC values (ranging from < 0.01 to 0.37).

Occupancy and Productivity --- Four nesting territories were occupied in the construction study location in the year following blasting, and all were successful. Occupancy of nesting territories in the construction study location in 1986 and 1987 was similar to occupancy rates during 1976-1978 when a complete survey was conducted (Fisher exact test, 1-sided, 1986: $P = 0.31$; and 1987: $P = 0.31$). Two of 4 pairs produced young in 1986 (1.8 ± 2.1 young fledged/pair); in 1987, 4 pairs successfully fledged young (5.0 ± 0.0 young/pair).

Ten nesting territories were surveyed in the blasting study location in 1985, 1986, and 1987 (Appendix 3). All 4 nesting territories in the blasting study location that were exposed to blasting in 1985 were occupied in 1986. One nesting territory was occupied in early spring but was later vacated; the other 3 were successful. In 1987 only 1 of the 4 nesting territories was occupied and successfully produced young (Reynolds Upper Road); the other 3 nesting territories were vacant. I compared occupancy rates at nesting territories exposed to experimental blasting with those that were not. On a yearly basis occupancy rates were similar between these 2 groups (Fisher exact tests, 1-sided, 1985: $P = 0.60$; 1986: $P = 0.60$; and 1987: $P = 0.26$). Likewise, when all years were combined occupancy was similar for nesting territories exposed to blasting and those that were not (Fisher exact test, 1-sided, $P = 0.60$).

Table 28. Stepwise discriminant analysis to test for differences in behaviors of male and female prairie falcons (expressed as percentages of total observation time/day) nesting in the blasting and control study locations for the incubation ($n = 41$ days) and brood-rearing ($n = 51$ days) stages, 1985 (n denotes the number of observation days used in the analysis).

	Incubation						Brood-rearing					
	Male			Female			Male			Female		
Variables	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2
Perching	4.96	0.03	0.11	0.17	0.67	<0.01	4.34	0.04	0.08	4.46	0.03	0.08
Preening	1.11	0.29	0.03	2.37	0.13	0.05	5.59	0.02	0.10	0.43	0.51	<0.01
Incubating	0.05	0.82	<0.01	0.05	0.81	<0.01	-	-	-	-	-	-
Brooding	-	-	-	-	-	-	2.54	0.11	0.04	0.97	0.32	0.02
Nest visit	2.29	0.13	0.05	-	-	-	0.02	0.88	<0.01	1.97	0.16	0.03
Canyon flight	0.01	0.91	<0.01	0.13	0.71	<0.01	4.95	0.03	0.09	4.90	0.03	0.09
Out-of-canyon	0.70	0.40	0.01	1.85	0.18	0.04	0.44	0.51	<0.01	0.21	0.64	<0.01
Out-of-view	4.53	0.03	0.10	10.42	<0.01	0.21	1.75	0.19	0.03	1.28	0.26	0.02
ASCC		0.11			0.36			0.21			0.25	

Table 29. Stepwise discriminant analysis to test for differences in behaviors of male and female prairie falcons (expressed as counts/day) nesting in the blasting and control study locations for the incubation (n = 41 days) and brood-rearing (n = 51 days) stages, 1985 (n denotes the number of observation days used in the analysis).

	Incubation						Brood-rearing					
	Male			Female			Male			Female		
Variables	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2
Nest visit	2.84	0.09	0.06	-	-	-	<0.01	0.96	<0.01	2.37	0.12	0.04
Patrolling	4.41	0.04	0.10	0.86	0.35	0.02	2.36	0.13	0.04	0.77	0.38	0.01
Aggression	5.80	0.02	0.12	2.06	0.15	0.05	6.55	0.01	0.11	4.64	0.03	0.08
Copulation	0.85	0.36	0.02	1.43	0.23	0.03	0.18	0.66	<0.01	0.10	0.74	<0.01
Relocation	0.30	0.58	<0.01	1.63	0.20	0.04	8.36	<0.01	0.14	0.01	0.88	<0.01
Feeding adult	<0.01	0.94	<0.01	0.24	0.62	<0.01	3.51	0.06	0.06	2.24	0.14	0.04
Feeding chick	-	-	-	-	-	-	2.19	0.14	0.04	1.00	0.32	0.02
Prey delivery	<0.01	0.78	<0.01	1.05	0.31	0.02	1.05	0.31	0.02	0.06	0.80	<0.01
Prey cached	0.08	0.06	0.08	0.23	0.63	<0.01	0.21	0.64	<0.01	5.82	0.01	0.10
Prey retrieved	<0.01	0.99	<0.01	<0.01	0.97	<0.01	6.56	0.01	0.11	0.09	0.75	<0.01
ASCC		0.37			<0.01			0.37			0.27	

Productivity of the 4 nesting territories exposed to experimental blasting averaged 3.5 ± 1.3 young fledged/nesting territory in 1985, 1.8 ± 1.3 young fledged/nesting territory in 1986, and 1.3 ± 2.5 young fledged/nesting territory in 1987. The total number of young fledged from the 4 nesting territories dropped from 14 in 1985 to 7 in 1986 and to 5 in 1987.

Behavioral Reaction of Falcons to Observers

Observer Exchange at Blinds

Falcons showed no noticeable response to an arriving or departing observer in 926 of 1156 (80.1%) instances (Table 30). Differences were not found in response rate among years ($X^2 = 1.24$, df = 2, $P = 0.53$). Therefore, in subsequent analyses data were pooled over all years. Females showed a higher response rate than males for the pre-incubation stage (Fisher exact test, $P = 0.02$), but not for the incubation and brood-rearing stage (Fisher exact test, $P = 0.81$, and $P = 0.09$, respectively) (Table 31). When all nesting stages were combined, response rates were again higher for females than for males (Fisher exact test, $P = 0.03$). Response rates also differed among nesting stages ($X^2 = 16.32$, df = 3, $P = 0.001$) and among study locations ($X^2 = 9.73$, df = 3, $P = 0.02$). Study locations did not differ in response rates for 1985 and 1986 ($X^2 = 3.61$, df = 3, $P = 0.30$; and $X^2 = 4.17$, df = 2, $P = 0.12$). In 1987, however, a higher than expected response rate was found in the control study location, and a lower than expected rate in the construction study location ($X^2 = 6.51$, df = 2, $P = 0.04$).

In 1985, 13 of 16 blinds were accessed by foot; the remaining 3 were reached by driving a motorcycle and walking the last 30-100 m. Responses of falcons did not differ between means of access to the blinds, either by walking, or a combination of riding and walking ($X^2 = 0.19$, df = 1, $P > 0.25$; Table 32). In subsequent years observers always approached blinds on foot, and vehicles were not used within 400 m from the aerie. In 791 of 1947 instances (40.6%) male or female falcons were outside the canyon, or out-of-view. When falcons were

Table 30. Behavior changes by male and female prairie falcons when observers were approaching or leaving blinds, 1985-1987.

	No change		Change		Total
Sex	%	n	%	n	n
Male	77.0	376	23.0	112	488
Female	82.3	550	17.7	118	668
Both sexes	80.1	926	19.9	230	1156

Table 31. Behavior changes by male and female prairie falcons when observers were approaching or leaving blinds for each nesting stage, in instances when falcons were present in the nesting territory, 1985-1987 (numbers in parentheses are percentages of the total number of exchanges).

	Pre-incubation			Incubation			Brood-rearing		
Sex	No Change	Change	Total	No change	Change	Total	No change	Change	Total
Male	22 (71.0)	9 (29.0)	31	210 (83.3)	42 (16.7)	252	140 (70.4)	59 (29.6)	199
Female	90 (89.1)	11 (10.9)	101	235 (84.2)	44 (15.8)	279	216 (77.4)	63 (22.6)	279
Total	112 (84.9)	20 (15.1)	132	445 (83.8)	86 (16.2)	531	356 (74.5)	122 (25.5)	478

Table 32. Behavior changes of prairie falcons when observers were approaching or leaving blinds using different modes of transportation, 1985 (*n* denotes the number of instances during observer exchanges).

Transportation	No Change		Change		*n*
	%	(*n*)	%	(*n*)	
Motorcycle and walking	92.5	(37)	7.5	(3)	40
Walking	90.2	(119)	9.8	(13)	132
Overall	90.7	(156)	9.3	(16)	172

present, common behaviors the birds were engaged in were perching ($n = 495$), incubating ($n = 377$), brooding ($n = 89$), preening ($n = 84$), and flying in canyon ($n = 51$) (Table 33). Usually (80.4% of all instances) falcons continued these behaviors when blinds were approached.

The distance from the blind to the aerie apparently did not affect the behaviors of the falcons. The percent of the total number of instances that observers were approaching or leaving blinds associated with a change in falcon behavior per nesting territory was not significantly related to the distance from the blind to the aerie for all years combined (partial $b = -0.0003$, $t = -0.40$, $P = 0.69$). The response rate, however, increased with longer approach times (partial $b = 0.03$, $t = 2.35$, $P = 0.02$). Similar results were found for each of the years separately (Table 34).

The question remained whether the number of observed changes in behavior differed from the number of behavioral changes expected during the period that observers were approaching or leaving the blind. A higher rate of change would suggest a reaction of the falcons to an observer approaching or leaving a blind. The expected number of behavioral changes per hour

Table 33. Behaviors of prairie falcons when observers were approaching or leaving blinds, excluding instances when falcons were not present in the nesting territories, 1985-1987.

Prior to Approach		During Approach	
Behavior	*n*	Behavior	*n*
Perching	495	Perching	403
		Relocation	40
		Preening	13
		Aggression	13
		Incubating	8
		Out-of-canyon	7
		Flight-in-canyon	6
		Feeding	2
		Brooding	1
		Nest visit	1
		Out-of-view	1
Incubating	377	Incubating	355
		Relocation	8
		Perching	6
		Flight-in-canyon	3
		Out-of-canyon	2
		Preening	2
		Aggression	1
Brooding	89	Brooding	84
		Aggression	2
		Perching	1
		Flight-in-canyon	1
		Relocation	1
Preening	84	Preening	57
		Perching	13
		Relocation	5
		Out-of-view	4
		Flight-in-canyon	2
		Aggression	1
		Incubating	1
		Nest visit	1

Table 33. *continued*

Prior to Approach		During Approach	
Behavior	*n*	Behavior	*n*
Flight-in-canyon	51	Flight-in-canyon	7
		Perching	19
		Out-of-canyon	9
		Aggression	5
		Out-of-view	5
		Incubating	3
		Brooding	1
		Patrolling	1
		Feeding chick	1
Feeding chick	20	Feeding chick	14
		Out-of-canyon	2
		Relocation	4
Relocation	18	Relocation	5
		Perching	5
		Incubating	4
		Preening	2
		Nest visit	1
		Out-of-canyon	1
Aggression	11	Aggression	5
		Perching	4
		Incubating	1
		Out-of-canyon	1
Feeding adult	6	Feeding adult	3
		Perching	2
		Relocation	1
Patrolling	3	Patrolling	1
		Perching	2
Copulating	2	Copulating	0
		Perching	1
		Out-of-view	1
Total	1156		

was calculated using the frequency distribution of observed behavioral changes for male and female falcons per day for all years combined. This frequency distribution did not deviate significantly from a Poisson distribution (X^2 = 17.03, df = 10, $0.05 < P < 0.10$). The average approach time to a blind was 6.6 ± 3.3 min (*n* = 1107), and the 95% confidence interval for approach times is 6.6 ± 6.4 min. The probability of 1 or more behavioral changes in this time interval equals 46.3% based on the earlier mentioned Poisson distribution. Thus, the observed percentage behavioral change in male and female falcons combined (19.9%) is well within the expected probability of at least 1 behavioral change during a blind approach and can be considered "normal" behavior.

Observing from within and outside a Blind

With few exceptions behaviors did not differ between mornings or between afternoons when observations were made from either within or outside a blind (Appendix 4 and 5). These analyses were conducted for male and female falcons separately and for each of the 3 nesting stages. Likewise, none of the multivariate comparisons of the behavioral repertoire between mornings or between afternoons for male or female falcons on which observations were made from within and outside a blind showed significant differences (Hotelling-Lawley *T*, *P*'s > 0.20).

Occupancy and Productivity

Occupancy of nesting territories in the 3 BOPA study locations was compared between the 2 periods 1976-1978 and 1984-1987 (Appendix 6). The period 1976-1978 was used as a comparison period because complete occupancy surveys were carried out in these years (M. N. Kochert, U.S. Bur. Land Manage., pers. commun.). Nesting territories located in the Halverson Lake area (Halverson Upper Lake, Halverson Dunes, and Halverson Trail) were excluded from these analyses because incomplete occupancy information was available during the years 1984-1987. Occupancy of nesting territories in each of the 3 BOPA study locations was similar between the 2 periods (Fisher exact test, 1-tailed, construction: $P = 0.37$; recreation: $P = 0.18$; and control: $P = 0.37$).

No significant differences in productivity were found among study locations for any of the years (1984: Wilcoxon 2-sample test, $z = 1.73$, $P = 0.08$; 1985: Kruskal-Wallis tests, $X^2 = 7.13$, df = 3, $P = 0.07$; 1986: $X^2 = 4.03$, df = 3, $P = 0.25$; and 1987: $X^2 = 6.60$, df = 3, $P = 0.08$), or for all years combined (Kruskal-Wallis test, $X^2 = 5.63$, df = 3, $P = 0.13$) (Table 35). The construction and recreation study locations differed in productivity among years (Kruskal-Wallis tests, $X^2 = 11.36$, df = 3, $P = 0.01$; $X^2 = 11.22$, df = 3, $P = 0.01$). Such results, however, were not found for the control and blasting study locations (Kruskal-Wallis tests, $X^2 = 0.33$, df = 2, $P = 0.84$, and $X^2 = 0.82$, df = 2, $P = 0.66$). Productivity was higher in the construction study location in 1987 than in 1986, but not compared to 1984 and 1985 (nonparametric multiple comparison, $P = 0.05$). In the recreation study location productivity was higher in 1985 than in 1986, but differences between other years were not found (nonparametric

Table 34. Multiple regression analysis relating percent behavioral change recorded per nesting territory to distance from the blind to the aerie and average approach time for each blind, 1985-1987.

Year	Variable	Estimate	SE	*t*	*P*	r^2
1985	Intercept	-0.06	0.47	-0.14	0.88	0.09
	Distance	0.0002	0.001	0.13	0.89	
	Approach time	0.06	0.05	1.19	0.25	
1986	Intercept	0.28	0.12	2.17	0.05	0.54
	Distance	-0.00008	0.0006	-0.13	0.90	
	Approach time	0.02	0.008	3.06	0.01	
1987	Intercept	0.28	0.27	1.04	0.32	0.09
	Distance	0.0002	0.001	0.13	0.90	
	Approach time	0.02	0.02	1.02	0.33	
Years pooled	Intercept	0.23	0.17	1.38	0.17	0.15
	Distance	-0.0003	0.0008	-0.40	0.69	
	Approach time	0.03	0.01	2.35	0.02	

Table 35. Productivity (young fledged/pair*) of prairie falcons nesting in the 4 study locations, 1984-1987 (*n* refers to the number of occupied nesting territories).

	Construction		Recreation		Control		Blasting		Total	
Year	Mean ± SD	(*n*)	Mean ± SD	(*n*)	Mean ± SD	(*n*)	Mean ± SD	(*n*)	Mean ± SD	(*n*)
1984	3.6 ± 0.9	(5)	2.2 ± 1.5	(6)	- -	-	- -	-	2.8 ± 1.4	(11)
1985	3.0 ± 2.0	(4)	4.0 ± 1.4	(7)	3.5 ± 1.7	(4)	1.6 ± 2.0	(9)	2.8 ± 2.0	(24)
1986	1.8 ± 2.1	(4)	0.9 ± 1.6	(7)	3.0 ± 1.9	(5)	1.9 ± 1.8	(7)	1.8 ± 1.8	(23)
1987	5.0 ± 0.0	(4)	3.1 ± 2.0	(8)	2.8 ± 2.6	(5)	2.6 ± 2.4	(5)	3.3 ± 2.1	(22)
Total	3.4 ± 1.8	(17)	2.6 ± 2.0	(28)	3.1 ± 2.0	(14)	1.9 ± 2.0	(21)	2.7 ± 2.0	(80)

* 1st nesting attempt not included in young fledged/pair calculations.

multiple comparison, $P = 0.05$). When productivity was compared among years only for falcons nesting in the BOPA, productivity was significantly lower in 1986 than in 1985 and 1987, but differences among other years were not found (Kruskal-Wallis test, $X^2 = 12.08$, df = 3, $P = 0.007$; nonparametric multiple comparison, $P = 0.05$). Productivity of prairie falcons was not correlated with the human activity index ($r_T = 0.03$, $P = 0.76$, $n = 54$ nesting attempts).

Hatch dates did not differ among study locations for any year (1984: Wilcoxon 2-sample test, $z = 0.09$, $P = 0.92$; 1985: Kruskal-Wallis test, $X^2 = 5.04$, df = 3, $P = 0.16$; 1986: $X^2 = 0.39$, df = 3, $P = 0.94$; and 1987: $X^2 = 5.62$, df = 3, $P = 0.13$) (Table 36). Differences in hatch dates among years were found for the construction, recreation, and blasting study locations (Kruskal-Wallis test, $X^2 = 6.90$, df = 3, $P = 0.07$; $X^2 = 6.86$, df = 3, $P = 0.07$; and $X^2 = 6.65$, df = 2, $P = 0.03$, respectively), but not for the control study location ($X^2 = 4.50$, df = 2, $P = 0.10$). Hatch dates were later in 1986 than in 1987 for the construction, recreation and blasting study locations, but were similar in 1984 and 1985 (nonparametric multiple comparison, $P = 0.05$). Similar results were found when hatch dates were compared among years only for the 3 BOPA study locations (Kruskal-Wallis test, $X^2 = 17.05$, df = 3, $P = 0.0007$). Productivity of prairie falcons nesting in the BOPA declined with hatch taking place progressively later in the year (t-test slope, $b = -4.93$, $t = 46.67$, $P = 0.0001$; $r^2 = 0.33$) (Fig. 25).

Table 36. Estimated Julian hatch day of prairie falcon clutches in the 4 study locations, 1984-1987 (*n* refers to the number of nesting attempts).

Nesting	Construction			Recreation			Control			Blasting			Total		
season	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
1984	126	± 13	(5)	128	± 10	(6)	-	-	-	-	-	-	127	± 11	(11)
1985	129	± 6	(4)	128	± 8	(7)	131	± 4	(4)	138	± 7	(4)	131	± 8	(19)
1986	146	± 25	(4)	143	± 10	(4)	139	± 14	(5)	139	± 7	(7)	141	± 14	(20)
1987	117	± 4	(5)	124	± 8	(6)	120	± 16	(5)	127	± 3	(3)	122	± 10	(19)
Total	129	± 17	(18)	130	± 11	(23)	130	± 15	(14)	136	± 8	(14)	131	± 13	(69)

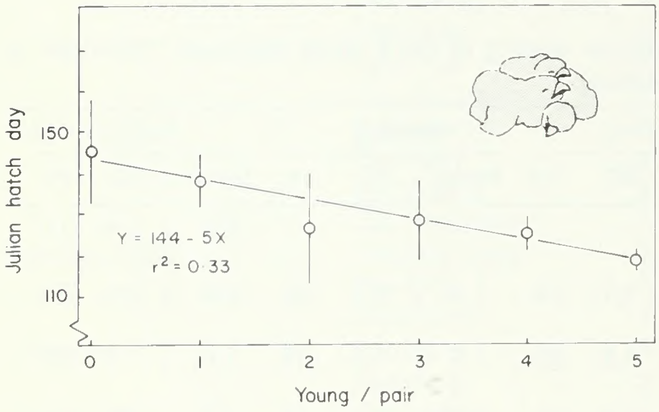


Fig.25 Julian hatch day regressed on prairie falcon productivity, 1984-1987.

A nest failure was defined as the termination of a nesting attempt by a falcon pair followed by desertion of the aerie. Over the period 1984-1987, 14 of 54 nesting attempts observed in this study failed (25.9%; Table 37 A). The failure rate was highest in 1986 (7 of 14 attempts; 50%), followed by 1987 (5 of 16 attempts; 31.2%), 1984 (1 of 8 attempts; 12.5%), and 1985 (1 of 16 attempts; 6.3%). Nest failures occurred in all BOPA study locations. Three failures were recorded both in the construction and control study locations, but 8 occurred in the recreation study location, 5 of which took place in the Halverson Lake area (Table 37 B). The Halverson Lake area was exposed to high levels of recreational activity. Also, the canyon wall is more accessible in this part of the BOPA than in the construction and other sections of the recreation study location (Dedication Overlook). The 5 nesting attempts recorded in 1986 and 1987 included 2 pairs which each failed twice. For their 2nd attempt both pairs moved (50-150 m) to a new location near the original scrape.

The cause of failure could not be determined with certainty for any of the nesting attempts. Low prey delivery rates were observed in some instances (Table 37 B). Several pairs started incubating late in the season and may have experienced unfavorable prey conditions. In 2 instances the male falcon was not observed for an entire observation day; shortly thereafter the female abandoned the nesting attempt. Others nested on open ledges or stick nests which may be subject to higher predation rates (Ogden and Hornocker 1977). Of the 54 observed nesting attempts, 10 were in open aeries, and 3 of those failed. However, nests on open ledges did not have a higher failure rate than those in cavities in this study (Fisher exact test, $P = 1.00$). The behavioral repertoire of falcon pairs which

Table 37. Nest failures in the 4 study locations by (A) study location and (B) nesting territory, 1984-1987 (number of nesting attempts in each study location in parentheses).

A.

	Year				
Study location	1984	1985	1986	1987	1984-87
Construction	0 (4)	1 (4)	2 (4)	0 (4)	3 (16)
Recreation			4 (6)	3 (7)	8 (21)
Dedication Overlook	1 (4)	0 (4)	2 (4)	0 (4)	3 (16)
Halverson Lake	-	-	2 (2)	3 (3)	5 (5)
Control	-	0 (4)	1 (4)	2 (5)	3 (13)
Blasting	-	0 (4)	-	-	0 (4)
Total	1 (8)	1 (16)	7(14)	5 (16)	14 (54)

Table 37. *continued*

B.

Year	Study location	Day	Stage	Remarks
1984	Recreation	29	Brood-rearing	Low prey delivery rate (Priest Rapids I)
1985	Construction	5	Brood-rearing	Open stick nest (Ferry)
1986	Construction	17	Brood-rearing	Late nesting attempt (Falcon Flats Black Rock)
1986	Construction	27	Incubation	Late nesting attempt (Falcon Flats Fingers)
1986	Recreation	23	Brood-rearing	Unknown (PF II)
1986	Recreation	3	Incubation	Male falcon disappeared (Dedication Site)
1986	Recreation	0	Incubation	Open stick nest (Halverson Upper Lake)
1986	Recreation	0	Incubation	Late 2nd attempt (Halverson Upper Lake)
1986	Control	5	Brood-rearing	Aerie in unstable cliff (San Sebastian Basin)
1987	Recreation	15	Incubation	Open stick nest (Halverson Dunes)
1987	Recreation	9	Incubation	Male falcon disappeared (Halverson Trail)
1987	Recreation	21	Incubation	Late 2nd attempt (Halverson Trail)
1987	Control	-3	Pre-incubation	Male falcon disappeared; low prey delivery rates (Tick City)
1987	Control	27	Incubation	"Normal" nesting attempt (Tick III)

failed in their nesting attempt was similar to that of successfully breeding pairs in the control study location (0.01 < ASCC's < 0.37).

Weights of Nestlings

Nestlings were an average 31 ± 2 days of age (*n* = 148 young) when weighed. The sex ratio of banded falcons (82 males and 66 females) did not deviate from equality ($X^2 = 1.72$, df = 1, $P > 0.10$). Females were an average 1.4 times heavier than males and larger for all morphological measurements except length of the 7th primary (Table 38). Tarsus thickness, wing chord length, and footpad length were the best predictors of male weight ($r^2 = 0.35$). The best predictors of female weight were tarsus thickness, wing chord, and cere depth ($r^2 = 0.55$). Weights of nestlings were not scaled using morphological measurements, because none of these measurements were highly correlated with nestling weight.

Weights of prairie falcon young measured in the BOPA in 1987, but outside the BOPA study locations (i.e., the "comparison study location"), were used as a comparison data base for weights of young in the study locations in 1986 and 1987 (Table 39). Weights differed among study locations for each year and sex separately (Kruskal-Wallis tests, 1986: males $X^2 = 16.68$, df = 4, $P = 0.02$, females $X^2 = 10.15$, df = 4, $P = 0.0003$; 1987: males $X^2 = 15.75$, df = 4, $P = 0.003$, females $X^2 = 17.68$, df = 4, $P = 0.001$). In 1986 significantly lower weights were recorded for males in the recreation and control study locations than in the construction, blasting, and comparison study locations (nonparametric multiple comparison $P = 0.05$). For females, however, the nonparametric multiple comparison test was not able to determine differences among study locations. In 1987 weights of males in the control study location were significantly lower than in the comparison study location. The multiple comparison test was unable to distinguish differences in weight among the construction, recreation, and blasting study locations. For females weights were significantly lower in the control study location than in the comparison, construction, and recreation study locations. This test was not able to determine in which group the blasting study location could be placed. Weights of male and female young also differed among 1986, 1987, and the comparison study location for the construction, recreation, and control study locations, but not for the blasting study location (Table 39). In the construction study location weights of nestling males were lower in 1986 than in the comparison study location, but similar to 1987. Nestling females in the construction study location were lower in weight in 1986 than in 1987 and in the comparison study location. In the recreation study location males were lower in weight in 1986 than in 1987 and in the comparison study location. For both male and female nestlings in the control study location weights were similar in 1986 and 1987, but lower than in the comparison study location. Differences in weights among

Table 38. Weights (g) and morphological measurements (mm) of nestling male (n = 82) and female (n = 66) prairie falcons, 1986 and 1987.

	Male		Female				
Variable	Mean	SD	Mean	SD	t*	df	P
Weight	530	58	758	103	-16.01	98	<0.001
Tarsus length	59.7	4.4	65.6	6.0	-6.59	117	<0.001
Tarsus lateral width	6.3	0.3	7.7	0.5	-19.13	102	<0.001
Tarsus dorsal width	7.2	0.5	8.7	0.6	-14.72	123	<0.001
Wing chord length	200	20	208	22	-2.61	146	0.01
7th primary length	126	19	124	20	0.66	146	0.50
Culmen width	9.3	0.9	10.5	1.2	-7.10	119	<0.001
Culmen depth	13.1	0.8	15.1	0.5	-17.88	139	<0.001
Culmen length	16.9	0.8	19.2	1.2	-13.22	112	<0.001
Footpad length	75.8	3.2	88.0	5.4	-16.34	100	<0.001

* Test statistic to determine differences in weight and morphology between sexes.

Table 39. Weights (g) of male and female prairie falcon nestlings in the 4 study locations (n refers to the number of young weighed).

		Construction			Recreation			Control			Blasting		
Sex	Year	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
	1986	518	± 46	(2) b**	307	± 115	(2) b	464	± 33	(5) b	544	± 41	(5)
Male	1987	529	± 34	(14) a,b	536	± 30	(15) a	470	± 18	(4) b	541	± 35	(5)
	1987*	558	± 43	(30) a	558	± 43	(30) a	558	± 43	(30) a	558	± 43	(30)
		X^2	= 5.27		X^2	= 8.20		X^2	= 17.92		X^2	= 0.71	
		P	= 0.07		P	= 0.01		P	= 0.0001		P	= 0.69	
	1986	700	± 51	(5) b	559	± 259	(3) a	673	± 140	(8) b	739	± 79	(5)
Female	1987	816	± 49	(10) a	815	± 40	(14) a	706	± 8	(4) b	737	± 31	(4)
	1987*	801	± 47	(13) a	801	± 47	(13) a	801	± 47	(13) a	801	± 47	(13)
		X^2	= 10.56		X^2	= 2.25		X^2	= 9.36		X^2	= 6.28	
		P	= 0.005		P	= 0.32		P	= 0.009		P	= 0.04	

* Comparison data base which includes nestling weights of falcons in nesting territories in the BOPA, but outside the BOPA study locations.

** Means followed by the same letter(s) do not differ significantly among study locations at $P = 0.05$ (nonparametric multiple comparison).

1986, 1987, and the comparison study location were not found for female nestlings in the recreation study location and for either male or female nestlings in the blasting study location (Table 39). However, interpretation of the results of the statistical tests have to be made with caution, because sample sizes were usually small and the probability of a Type II error high.

To avoid sample size problems another approach was used by pooling nestling weights by sex for each year (Table 40). A comparison was made for males and females separately among the blasting study location (1986 and 1987), the BOPA study locations (1986 and 1987), and the comparison study location (1987). In both male and female nestlings the lowest weights were recorded in 1986 for young in the BOPA and the highest weights for nestlings in the 1987 comparison study location (ANOVA, $F = 10.45$, df = 4 and 77, $P = 0.0001$; and ANOVA, $F = 7.64$, df = 4 and 61, $P = 0.0001$; Table 40).

No significant correlations were found between mean weight of male and female young per brood and an index of human activity for each nesting territory ($r_T = 0.06$, $P = 0.75$, $n = 13$ broods; and $r_T = 0.08$, $P = 0.62$, $n = 17$ broods, respectively).

Table 40. Weights (g) of male and female prairie falcon young hatched in the comparison, BOPA, and the blasting study locations (*n* refers to the number of young weighed).

Sex	Year	Study location	Weight Mean	SD	*n*	DMR
Male	1987	Comparison	558	43	30	a*
	1986	Blasting	544	41	5	a
	1987	Blasting	541	35	5	a
	1987	BOPA	525	37	33	a
	1986	BOPA	441	94	9	b
Female	1987	Comparison	801	47	13	a
	1987	BOPA	800	56	28	a
	1986	Blasting	739	79	5	a,b
	1987	Blasting	737	31	4	a,b
	1986	BOPA	660	146	16	b

* Means followed by the same letter(s) do not differ significantly among study locations at $P = 0.05$, based on Duncan's multiple range test.

Discussion

Construction and Recreational Activities

Behaviors of male and female falcons did not show strong and consistent relationships with the number of visitors and traffic in the construction and recreation study locations (Table 41). Some associations were found, notably a positive association between patrolling and human activity during incubation and brood-rearing for female falcons and during pre-incubation for males. Male falcons showed a negative association between patrolling and human activity during brood-rearing and aggression during incubation. However, these associations appear to be more related to behavioral changes over the nesting season than to human activities, as will be discussed later. Also, these associations do not necessarily represent causal relationships; some associations are purely coincidental. For instance, both a disturbance index and certain behaviors can decrease over time independently and appear associated with each other through factor analysis. The entire behavioral repertoire of male and female falcons did not show a relationship with construction, recreation, or blasting activities. The behavioral repertoire of falcon pairs showed considerable individual variation (e.g., many nesting territory effects were found) and differed substantially among years. Therefore, it is unlikely that either of the multivariate analyses used was sensitive enough to detect subtle changes in behavior. Univariate analyses for each of the falcon behaviors separately seem more promising in uncovering aberrant behavior related to human activities (Table 41), particularly for behaviors that vary within narrow limits (e.g., incubation), or are otherwise critical in a successful nesting attempt (e.g., brooding, nest defense, and prey deliveries).

Copulations during pre-incubation averaged 3.8 ± 0.3 (SE) per day, or an estimated 194 ± 15 copulations over the pre-incubation period. Copulation timing and sequence of prairie falcons in this study were similar to those of peregrine falcons (Ratcliffe 1980). The number of copulations appeared more than adequate to ensure fertilization of the eggs. High copulation frequencies may also serve to maintain the pair bond and synchronize breeding behavior between the sexes (Wrege and Cade 1977; McKinney et al. 1984; Birkhead et al. 1987; Møller 1987a,b; Holthuijzen et al. 1988). Copulation frequencies were similar among study locations and years, and there was no indication that they were affected by human activities.

Prairie falcons rapidly increased the amount of time incubating after clutch completion. Little variation is allowed in time spent incubating to keep the eggs at

Table 41. Summary of univariate analyses, and predicted and observed effects of human activities on falcon behaviors, occupancy, productivity, and weight of young.

	Differences among					Correlated with human activity	Hypothesized effects of Human Activities	
Variable	Study location	Year	Nesting stage	Study location by year	Study location by nesting stage		Predicted	Observed
Copulation	no	no	yes	-	-	yes	lower	no change
Incubation	no	no	-	no	-	-	lower	no change
Brooding	no	no	-	no	-	-	lower	no change
Prey delivery	no	yes	yes	yes	no	no	lower	no change
Relocation	yes	yes	yes	yes	-	no	higher	higher
Perching								
Male	yes	yes	yes	yes	yes	no	higher/lower	variable
Female	yes	yes	yes	yes	yes	no	higher/lower	variable
Aggression	yes	yes	yes	yes	yes	no	higher/lower	variable
Patrolling	yes	yes	yes	yes	-	no	higher/lower	higher
Absence	no	yes	yes	no	yes	-	higher	no change
Occupancy	no	-	-	-	-	-	lower	no change
Productivity	-	yes	-	no	-	no	lower	no change
Weight								
Male	yes	yes	-	yes	-	no	lower	variable
Female	yes	yes	-	yes	-	no	lower	variable

optimal temperature once full incubation is reached (Drent 1975, Schwartz et al. 1977). Percent of the day incubating in prairie falcons remained stable at about 97%, which is similar to values found for other free-living birds. Matray (1974) estimated that 2 broad-winged hawk (*Buteo platypterus*) pairs attended eggs for 96.7% of the day. Drent (1975) reported values of 98% in dunlin (*Calidris alpina*) and 92% in yellow-billed magpies (*Pica nuttalli*). Female falcons probably did most if not all of the nocturnal incubating. Effects of study location were not found; only in 1987 was the average percent incubation/pair/day slightly higher (about 1%) in the construction study location than in the recreation and control study locations.

In 2 studies, researchers entered prairie falcon aeries containing eggs or young without affecting productivity (Steenhof and Kochert 1982, Grier and Fyfe 1987). In the latter study the eggs were not incubated for 15 to 40 min. Apparently, prairie falcon eggs can be unattended without measurable effects for longer periods than observed in this study. Also, prairie falcon aeries are usually situated in small cavities or potholes that shelter the eggs (and later young) from the sun and wind. Although the percent of the day spent incubating/pair varied little, considerable variation was found in the percent of the day males and females incubated. Males incubated an average 33% of the day, but sometimes up to 76% of the day. Females incubated an average 62% of the day, but sometimes as little as 16% of the day. Kaiser (1986) reported that male prairie falcons incubated 22% of the daylight hours and females 74% ($n = 105$ hours). Wild peregrine males incubated 44% of the day and females 52% of the day (Hunt 1979). Incubation values for prairie falcons generally agree with these studies.

Role partitioning showed considerable plasticity in this study. Some males delivered few prey items to the female, but incubated for considerable amounts of time, whereas other males provided most of the prey, but spent little time incubating. Apparently, the system breaks down when the mate fails to relieve the incubating bird. This was observed in 3 failed nesting attempts. In 1987 a female at Halverson Lake incubated the entire day and night, but the aerie was abandoned 1 week later. A similar event occurred in 1986 in the recreation study location below Dedication Overlook. In 1987 a male in Tick Basin seemed to be a poor provider and spent very little time inside the aerie. The female abandoned her partly completed clutch when the male failed to return during an entire day. In all cases, it remained unclear why the male disappeared.

Brooding in prairie falcons rapidly decreased over time from almost 90% of the day just after hatch to about 9% when the young were 2.5 weeks old. Females did most of the brooding. Similar observations were made with peregrine falcons (Enderson et al. 1973, Ratcliffe 1980). Also, peregrine falcon males brooded only for short periods of time (Enderson et al. 1973, Hovis et al. 1985). Male prairie falcons, like peregrines, may be too small to adequately cover the nestlings and also seem less eager to brood (Ratcliffe 1980, Hovis et al. 1985). Females increased their time outside the canyon with a concomitant decrease in time spent brooding. Similar observations were made with harriers (*Circus* spp.) (Schipper 1973) and European sparrowhawks (*Accipiter nisus*) (Newton 1978). No differences in percent of the day brooding/pair regressed over time were found among study locations or among years. Thus, in behaviors critical to the production of young (e.g., copulation, incubation, and brooding) I could not detect any effects of human activities.

Behaviors important in raising young from hatch to fledgling stage include procurement of sufficient prey for the growing brood and protection against predators. When human activities interfere with feedings over an extensive time period, mortality of young may increase because of excessive weight loss or intensified sibling rivalry (Fyfe and Olendorff 1976, Am. Ornithol. Union 1988). In this study, neither prey delivery rates nor the prey procurement index differed among study locations when all years or all nesting stages were combined. In 1985 prey delivery rates in the blasting and control study locations were lower than in the construction and recreation study locations during incubation. In 1987, when construction was completed, prey delivery rates in the construction study location were lower than in the control and recreation study locations. These differences in prey delivery rates do not demonstrate an obvious relationship with human activities, which is further supported by a non-significant relationship between prey delivery rates during the nesting cycle and the index of human activity. Prairie falcons nesting in the blasting study location delivered relatively more avian prey and fewer ground squirrels than prairie falcons nesting in the BOPA study locations in 1985. Also, out-of-canyon time per delivered prey item was significantly higher in the blasting study location than in the BOPA study locations. This suggests that prairie falcons nesting in the blasting study location procured prey in lower quality habitat with respect to prey.

The various indexes of prey procurement (prey delivery rate, prey procurement index, out-of-canyon trips/pair/day) showed substantial differences among years. The trends were the same for all indexes and were strongest for the brood-rearing stage: values for 1986 and 1987 represented 2 extremes, with 1984 and 1985 in between. In 1987 prairie falcons made more successful trips out of the canyon of shorter duration than in 1986. The percent of Townsend's ground squirrels in the diet was closely associated with the time spent out-of-the canyon, i.e., relatively high in 1987 (53.2%), relatively low in 1986 (21.9%) and in between for 1984 (35.7%) and 1985 (30.6%). The question remains to what extent percent Townsend's ground squirrel in the diet of prairie falcons reflect prey densities. Prairie falcons may show a preference for Townsend's ground squirrels (Steenhof and Kochert 1988) and increase their hunting efforts as prey densities decline until it becomes energetically unrewarding. At this point other prey species are likely to become more important. Unfortunately, data on Townsend's ground squirrel abundance are incomplete over the course of this study. In 1987 hole counts, an index of Townsend's ground squirrel density, showed almost a doubling compared to hole counts conducted in 1986 (Peterson and Yensen 1986, Quinney et al. 1987). Prey delivery rates and falcon productivity were significantly higher in 1987 than in 1986, and the weights of the young were significantly lower in 1986 than in 1987. This suggests that in 1986 prey availability was considerably lower than in 1987. Young of 2 late broods (Camera and Tick I) showed stunted growth and poor development. One of these broods (Camera) showed evidence of cannibalism. The influence of weight of young prairie falcons near fledging on their subsequent survival is unknown. In European sparrowhawks, weight of young near fledging did not significantly influence their survival (Newton 1986). In other species, however, such as the great tit (*Parus major*), fledgling weight was positively associated with survival (Perrins 1979).

Estimated date of clutch completion was relatively late in 1986 and varied more widely than in other years of this study. Laying date has been reported to be affected by the condition of the female when arriving at the breeding grounds, the ability of the male to provide prey to the female, and prey abundance (Cavé 1968; Newton 1979, 1986, 1988; Dijkstra et al. 1982; Newton et al. 1983; Newton and Marquiss 1984; Simmons et al. 1986; Barnard et al. 1987; Meijer et al. 1988). Prey delivery rates during the pre-incubation stage regressed on laying date showed a significant negative relationship in 1986, but not for other years. In 1986 early nesting males (i.e., clutch completion before 15 April) spent more time outside the canyon presumably hunting (70.3%) than late nesting males (i.e., clutch completion after 15 April) (59.7%), and provided twice as much prey. In contrast, late nesting females spent a substantially larger amount of time out-of-the canyon during pre-incubation than early nesting females. During the pre-incubation and incubation stages, prey delivery rates for late nesting falcons in the BOPA were similar to prey delivery rates in 1985, when laying occurred early in the year. Apparently, in 1986 similar prey delivery rates were insufficient to induce early nesting. These observations suggest that the condition of the females may not have been optimal when they arrived in the BOPA. Early nesting only occurred when the male provided more than average numbers of prey during pre-incubation (which may suggest that the more proficient males were associated with early nesting). Similar situations have also been observed in several other raptors such as the European sparrowhawk and non-raptorial birds (Newton 1979, 1980, 1986, 1988). In addition, late nesting pairs faced decreasing prey availability due to gradual estivation of Townsend's ground squirrels from May through July. Low ground squirrel availability in 1986 may have aggravated the situation. Late nesting falcons showed much lower prey delivery rates than early nesting falcons of the same year or any other year during brood-rearing. This resulted in a decrease in productivity of progressively later nesting pairs.

The amount of time per day during which a pair was absent from the nesting territory and unable to defend the nesting territory showed 3 distinct stages coinciding with the 3 stages of the nesting cycle. Prairie falcons were progressively less absent from the nesting territory during pre-incubation, almost continuously present during incubation, and increasingly more absent during brood-rearing. Pairs were absent for a similar percent of the day in the 4 study locations during pre-incubation and incubation. During brood-rearing, percent absence was higher in the blasting study location than in the 3 BOPA study locations.

Aggression levels followed a trend similar to absence when all nesting stages were combined. Pairs in the blasting study location showed lower aggression levels than those in the 3 BOPA study locations. Nesting densities of common ravens, prairie falcons, and other raptors were substantially lower in the blasting study location than in the BOPA. Because frequency of attacks by prairie falcons increased with the nesting density of conspecifics and heterospecifics, lower levels of aggression recorded in the blasting study location probably result from fewer intrusions in their nesting territories, rather than a response to blasting. Differences among years in aggression levels and percent absence indicate that aggression levels tended to be higher when falcons were present in the nesting territory for longer periods of time. This in turn may be directly related to the physiological condition of the adult birds. When prey is abundant as appeared to be the case in 1987, more time is available for nest defense activities.

In 1986 the condition of the young was generally poor, and the adults were probably under stress to provide sufficient prey to their offspring. Prey procurement times were 1.5-3 times longer in 1986 than in 1987. In 1986 presence and aggressive behavior were low, and nest failures due to predation may have been more likely. The failure rate in the brood-rearing stage was higher in 1986 than in any other year, but a relationship between the absence of adult falcons and the disappearance of young remains tentative because of the small number of failures involved. It is significant that nest failures occurred in all BOPA study locations and that in 1985 nest failures were not recorded in the blasting study location where percent absence was higher than in the BOPA study locations. Thus, behaviors related to the protection and feeding of young exhibited patterns that did not appear to be associated with exposure to human activities.

Patrolling frequency did not follow trends in aggression. Patrols by nesting pairs peaked during pre-incubation, then declined and remained at approximately the same level during incubation and brood-rearing. Patrolling may function to establish and advertise nesting territories during pre-incubation, as has been reported for other raptors (Newton 1979, 1986). Once boundaries were established they were regularly patrolled during incubation and brood-rearing. The nesting density of other prairie falcons may influence patrolling frequency during pre-incubation, which could explain the lower patrolling frequencies recorded in the blasting and control study locations as compared to the construction and recreation study locations. This is further supported by similar patrolling frequencies among years for a particular study location during pre-incubation. Thus, patrolling frequencies may be characteristic of a specific study location, rather than related to human activities, which differed in intensity from year to year.

Perching and preening behavior showed much individual variation. Both males and females spent much of the day perched in the nesting territory, females usually more than males, particularly around egg-laying ("egg-laying lethargy", Newton 1979). Perching time rapidly decreased as females spent increasingly more time inside the aerie. The amount of time spent perching and preening and the number of relocations/pair/day were inversely related to percent absence from the nesting territory for each year. Percent perching for both males and females was always lower in the blasting study location than in the BOPA. The highest number of relocations/pair/day for all years combined was observed in the recreation study location, followed by the construction and control study locations. This is closely related to the amount of time spent perching and preening, which also tended to be higher in the recreation study location for both sexes.

Productivity did not appear to be affected by human activities because differences were not found among study locations for each of the years. Several investigators have reported that nesting raptors (e.g., gyrfalcons, peregrine falcons, and ferruginous hawks) disturbed during the year may successfully raise young, but may not use the same nesting territory in subsequent years (Fyfe and Olendorff 1976, Platt 1977, Ratcliffe 1980, White and Thurow 1985). Occupancy rates of prairie falcon nesting territories in the 3 BOPA study locations remained stable during the study and were similar to occupancy rates during 1976-1978. Likewise, occupancy rates at nesting territories exposed to experimental blasting compared with those that were not, were not significantly different. Thus, productivity and occupancy rates do not seem to be affected by human activities. Nest failures occurred in all BOPA study locations. Consistent failures were reported only near Halverson Lake, where recreational activity is high. However, I was unable to determine whether the poor performance of falcons nesting at Halverson Lake was related to human disturbance or other factors, such as the quality of hunting areas and nesting cliff characteristics.

Blasting

Nesting prairie falcons in the construction and blasting study locations showed no differences in their overall behavioral repertoire, productivity, and occupancy of traditional nesting territories. Falcons nesting in the blasting study location, however, showed longer readjustment times and reacted more frequently to blasting than pairs in the construction study location. These differences in readjustment time may be explained by differences between construction and experimental blasting. Construction blasting occurred farther away from the aeries than experimental blasting ($\bar{x}$ = 810 m versus $\bar{x}$ = 127 m). Demolition blasts were conducted underground although they involved charges 10-500x more powerful than those used in experimental blasting. Hence, noise levels at the aeries probably were lower. Construction blasting was associated with various types of continuous construction activities, and falcons in the construction study location were also exposed to high levels of recreation. Human activities in the blasting study location were limited to ranching. Frequent contact with human activities tends to make raptors less sensitive to additional disturbances (Newton 1979). Because prairie falcons show a high fidelity to their natal area (Platt 1981, Steenhof et al. 1984, Runde 1987), falcons nesting near Swan Falls Dam may have habituated to the presence of humans and their activities. In contrast, falcons in the more remote blasting study location were exposed to minimal human activities. Prairie falcons did not demonstrate a change in their readjustment time to blasting during the nesting cycle. Other raptor species exposed to human disturbance became less sensitive as the nesting cycle progressed (Newton 1979). Occupancy remained the same the year following experimental and construction blasting. However, I could not determine whether the same individuals re-occupied a nesting territory because the falcons were not individually marked.

Observer Disturbance

Investigators did not appear to affect the behaviors of prairie falcons by approaching observation blinds placed 70-250 m from the aeries, or by different modes of access. Sitter (1983) observed nesting prairie falcons from blinds placed between 2 and 160 m from the aeries. The falcons he observed were tolerant of activities of the observers and often resumed normal activities within minutes after construction of a blind. Furthermore, each observed aerie was visited by a researcher every 4th day to collect pellets. All but 1 of the studied aeries successfully fledged young. Steenhof and Kochert (1982) compared success rates of breeding prairie falcons disturbed early during incubation with those of pairs found early but not disturbed before young were 4 days old. They found that the success rates of pairs did not differ significantly between the 2 groups of falcons. Grier and Fyfe (1987) found no effects of researcher disturbance on breeding success of prairie falcons in Alberta. They climbed into treatment aeries at least once, from egg-laying through late brood-rearing, which took 15 to 40 min per visit. Olsen and Olsen (1978) recommended that biologists spend no more than 20-30 min at a peregrine falcon aerie containing eggs. It appears that prairie falcons do not easily abandon their reproductive effort, even when the aerie is repeatedly visited, and exhibit considerable tolerance to observer activity.

I found no appreciable difference between behavioral observations collected from within or outside a blind. Prairie falcons did not react to the presence of an observer. Nesting peregrine falcons in British Columbia, which were unlikely to have been exposed to much human activity, usually rapidly habituated to an observer in full view within 100 to 200 m of the nesting cliff (Nelson 1973). Thus, data collected from within or outside a blind are likely to be qualitatively and quantitatively similar, unless the blind restricts the observer's view of the nesting territory.

Overall Effect of Human Activities

Most predictions made earlier concerning the impact of human activities on prairie falcon behavior and nesting success were refuted by the results of this study

(Table 41). Even when the results seemed to agree with the predictions (relocation, patrolling), closer scrutiny revealed that the behaviors fluctuated with biotic factors rather than the intensity of human activities. Thus, it is clear that the range of human activities that prairie falcons were exposed to during this study is within the tolerance level of this species. Other disturbance studies on prairie falcons seem to report considerable variation in response. Several studies reported that entering the aeries of prairie falcons during incubation or brood-rearing had no noticeable effect on reproductive success (Steenhof and Kochert 1982, Sitter 1983, Grier and Fyfe 1987). Fyfe and Olendorff (1976) and Harmata et al. (1978) found that nesting prairie falcons were easily disturbed by human activities of low intensity over sustained periods of time. Boyce (1988) reported that productivity of prairie falcons nesting in the Mojave desert increased with a higher degree of remoteness of a falcon nesting territory to human activities. In Wyoming, a pair of prairie falcons nesting within 75 m of a coal mine, was exposed to blasting and operation of heavy equipment. The nesting territory was occupied for 3 consecutive years although none of the breeding attempts was successful (Bednarz 1984). In a New Mexico mountain range used for intensive mining and associated activities, prairie falcons were absent, whereas in 2 other similar, but undisturbed ranges several prairie falcon pairs were found (Bednarz 1984). The lack of historical data on nesting pairs and natural factors affecting prairie falcon nesting densities (e.g., prey abundance) limits interpretation of Bednarz's (1984) findings. Studies on other raptors showed considerable tolerance to human activities. Stahlecker and Alldredge (1976) reported that the potential productivity of 14 nesting territories of red-tailed hawks and golden eagles was reduced by 20% as a result of an underground nuclear explosion in which 22% of the nests were destroyed. Nest desertion, however, occurred at only 2 of 14 nests. Peregrine falcons and golden eagles have nested successfully a few hundred meters from high disturbance areas (e.g., blasting, construction, quarrying, mining sites, and airports) (Pruett-Jones et al. 1980, Haugh 1982, White and Thurow 1985, White and Emison 1988). Peregrine falcons nesting near the Alaska pipeline did not show a significant change in behaviors considered important in a successful nesting attempt (e.g., incubating, occupancy, or productivity) to simulated aerial surveillance and surface activities (Ritchie 1987). However, peregrine falcons in Alaska deserted their nests near locations where blasting took place for construction of a natural gas transportation system. The falcons habituated to construction, but not to blasting (U.S. Dep. Inter. 1976). Ferruginous hawks were very sensitive to experimentally controlled sound levels and in some cases abandoned their nests (White and Thurow 1985). These studies illustrate that the response of raptors to human activities may vary considerably among and within species (Newton 1979).

The critical factor determining population densities of prairie falcons and raptors in general appears to be the prey base (Newton 1976, 1979, 1980). Prey abundance and availability may compensate for the effects of disturbance by influencing the condition of the adult birds, their ability to procure prey, and therefore the survival of their young (van der Zande and Verstrael 1985, White and Thurow 1985, Newton 1980, 1986, 1988). Absence of direct persecution and abundance of prey can even make areas of high human activity attractive for settlement, as demonstrated by the establishment of peregrine falcons, European sparrowhawks, European kestrels, hobbies (*Falco subbuteo*) and merlins (*Falco columbarius*) in cities (Ratcliffe 1980; Newton 1979, 1986; White and Emison 1988).

Effectiveness of the Study Approach

Multivariate approaches did not appear very successful in elucidating relationships between human activities and falcon behaviors due to the considerable inter-individual variation in behaviors. Univariate analyses were more sensitive with respect to all criteria (i.e., falcon behavior, occupancy and productivity, and quality of the young), even though differences among years, nesting stages and the various combinations of years, nesting stages, and study locations made the analyses cumbersome and complex. However, the results allowed me to test the predictions made for each separate behavior and nesting success. No detectable effect of human activity was found on the measured variables that could not be attributed to biotic factors not related to construction or recreation.

In this study a considerable effort was made to determine the effects of human activities on the behaviors of nesting falcons. More than 9300 hours of observation were made during 632 days. Was the behavioral approach used in this study more effective than merely determining falcon productivity before, during, and after the impact? The behavioral data not only demonstrated that the impact of human activities investigated in this study were not detectable, but also provided alternative explanations for observed variation in productivity. For instance, the pronounced drop in productivity in 1986, when construction took place throughout the year, could have led to erroneous conclusions concerning the impact of construction on prairie falcon productivity. In most impact studies on birds of prey, the lack of information on natural variation in studied populations, and the possible causes of such fluctuations severely hamper the inferences that can be drawn. Behavioral observations made it possible to go beyond the descriptive phase and focus on other factors influencing prairie falcons.

This study demonstrated that some behaviors vary within narrow boundaries (e.g., percent of the day incubating/pair), whereas other behaviors exhibit considerable variation (e.g., percent of the day perching and number of relocations). The relatively stable behaviors appear to be particularly useful in evaluating human activities because small deviations would probably cause a nest failure. Also, key factors, both natural and man caused, affecting raptor behaviors can be identified and ranked according to their relative importance. Thus, behavioral observations can detect changes in particular behaviors and attribute these more reliably to natural background variation or effects of human activities than productivity data alone. This does not mean that productivity data in combination with density estimates of the prey cannot be an effective long-term monitoring tool for established raptor populations. It should be emphasized, however, that productivity is the final measure in studies evaluating the effects of human activities on raptor populations.

How sensitive is the behavioral approach and what sort of behavioral changes can be detected in spite of considerable individual variation in behavior? At first glance, it seems somewhat disturbing that the overall behavioral repertoire of pairs that failed was not significantly different from those that nested successfully. Changes in incubation behavior were observed, but only shortly before the nest was deserted. Such failures seem difficult to predict. It is not known what sort of changes would be associated with man-induced failures and whether these changes would be easy to detect. Although no differences in behaviors among study locations were found for each year separately, differences among years were detected in almost every behavior analyzed. Differences between 1986 and 1987 were easily identified, but those may have been associated with differences in prey densities. Differences between 1984 and 1985 were too small compared to the individual variation component. These differences illustrate the lower detection limit. Thus, to detect the effects of human activities on falcon behavior, they must be at least of the same order of magnitude as those found between 1986 and 1987.

Finally, there are a number of inherent problems with the experimental design of this study. The main problem is with pseudoreplication, defined by Hurlbert (1984) as the use of inferential statistics to test for treatment effects with data from experiments where either treatments are not replicated or replicates are not statistically independent. I could evaluate only 1 study location for each treatment (i.e., construction, recreation, control, and experimental blasting), a clear case of pseudoreplication. A 2nd problem concerns the repeated (and largely systematic) sampling over time of each of the observed prairie falcon pairs, which violates the assumption of independence of samples (or pseudoreplication in time). However, this problem may be the lesser of the 2 evils (James and McCulloch 1985). Hurlbert (1984) acknowledges that under certain conditions replication is virtually impossible. In those situations, field studies that involve unreplicated treatments may be the only or best option. Impact studies often have such characteristics. Replication of a particular treatment is in most cases out of the question (e.g., the construction of a dam), but a quantitative evaluation of the impact may be required (Stewart-Oaten and Murdoch 1986). Hurlbert (1984) argues that inferential statistics are improper in situations of pseudoreplication and should be avoided. Instead, he suggests that the investigator should use graphs and figures to present the collected information. Stewart-Oaten and Murdoch (1986), however, argue that graphs and figures are based on the same assumptions as the statistics used to test hypotheses. Thus, it is unclear how to proceed in situations where pseudoreplication cannot be avoided. By pointing out these problems in the design of the study, the reader will be aware of the shortcomings and potential limitations of some of the statistical analyses.

The amount of data collected in this study made it possible to rigorously analyze the data and test formulated hypotheses. In order to test hypotheses objectively reliance has to be placed on a probabilistic approach, i.e., statistics. Some doubt always remains although significant effects could not be detected. However, this is only an apparent paradox, because this question is inherent to the scientific method, which is intended to falsify hypotheses, not to prove these beyond doubt. The data collected in this study provide the basis upon which informed decisions can be made with a minimum of risk to the natural resource sought to be protected.

Conclusions And Management Implications

This study demonstrated that, in general, construction and recreation activities had no detectable adverse effects on nesting prairie falcons. The results give rise to the following specific management recommendations. I wish to emphasize that these recommendations pertain to the management of nesting territories per se, not foraging areas. Habitat alteration in foraging areas and disruption of falcon hunting may have serious effects on reproduction. The recommendations are also based on the assumption that nesting territories are not physically altered in any way. The falcon population in this study had been exposed to varying degrees of human activities prior to this investigation. Falcons nesting in remote areas may be more sensitive to human activities, and more restrictive guidelines may be necessary in those situations.

Major construction or development projects usually require an evaluation of environmental impacts. Such studies are often conducted over a short period, involve a minimum of field work, and have limited scientific or management value. Projects which may adversely affect a significant number of raptors should be evaluated by a field study that lasts several years. This study has demonstrated the necessity of examining a range of environmental factors and both project-related and non-project-related human activities. Such studies should involve observations during the pre-construction, construction, and post-construction periods, and observations made at 1 or more control areas that are as physiographically similar to the impact area as possible. This approach is not warranted for projects that affect a small number of raptors unless the raptors involved are members of a threatened or endangered species.

The results of this study suggest the following management implications:

1). Construction activities, including blasting and operation of heavy equipment, did not adversely affect behavior or productivity of falcons that nested at least 50 m above and at distances 550-1000 m from such activities.

2). Experimental or demolition blasting did not adversely affect the behavior or productivity of nesting prairie falcons. Nesting falcons were subjected to 3 experimental blasts per day, every other day for a total of 90 blasts throughout the nesting season. Small surface blasts beyond 125 m from occupied prairie falcon aeries need not be restricted during the nesting season, provided such blasts do not generate noise levels greater than 140 dB as measured at the aerie. Subterranean blasts up to 110 kg of dynamite, or its equivalent, may be allowed beyond 500 m from occupied prairie falcon aeries during the nesting season. Subterranean blasts up to 110 kg of dynamite, or its equivalent, beyond 500 m from occupied prairie falcon aeries. This study did not evaluate large sub-surface blasts capable of generating substantial ground tremors or shock waves. Hence, above recommendations may not apply in such cases.

3). Road improvement activities (i.e., roadbed preparation, paving, installation of guard rails) may be allowed beyond 100 m from occupied prairie falcon aeries during the nesting season, provided such traffic passes at least 50 m below the aeries.

4). Traffic flows of 200-235 vehicles per day, including trucks and other heavy equipment need not be restricted beyond 100 m from occupied prairie falcon aeries, provided such traffic passes at least 50 m below the aeries.

5). Activities potentially disturbing to nesting raptors (ORV use, target shooting, rolling boulders down cliffs, climbing on nesting cliffs) should be prohibited within 500 m of cliffs with occupied prairie falcon aeries. Recreational activities (i.e., fishing, sightseeing, camping, birdwatching, ORV use and target practicing) can be allowed beyond 500 m from the base of cliffs containing occupied prairie falcon aeries, provided such activities occur at least 50 m below the aeries.

6). Foot traffic need not be restricted beyond 150 m from the base of nesting cliffs containing occupied prairie falcon aeries, provided such traffic passes at least 50 m below the aeries. Restrictions do not have to be imposed on foot traffic that passes out of sight beyond the rim of cliffs containing occupied prairie falcon aeries.

7). Observation blinds do not have to be employed when observations are made beyond 150 m from the base of cliffs. Such observations should be made at least 50 m below aeries, and caution should be exercised when approaching or leaving an observation point.

8). Biologists can make nest visits up to 2 hours duration without causing adults to abandon the nesting attempt, or affecting condition and survival of young, provided nestlings are 30 days old, are fed, and visits take place during early morning or evening.

The last question I want to address concerns the applicability of these management recommendations to raptors other than prairie falcons. Extrapolation always involves risks because of the uniqueness of each species. Recommendations based on this study could possibly be extended to other species belonging to the family Falconidae and the genus *Falco*. In the genus *Falco*, species in the gyrfalcon group (prairie falcon, lanner falcon (*Falco biarmicus*), lagger falcon (*Falco jugger*), saker falcon (*Falco cherrug*), and gyrfalcon) and the peregrine group (Brown and Amadon 1969) offer the best potential for across species application of results obtained in this study. The prairie falcon is considered to be a descendant of the same ancestral lineage as the lagger falcon of south Asia and taxonomically has much in common with the saker falcon of east Asia and northwest Africa (Palmer 1988). However, due to lack of information on the ecology of the lagger and saker falcon it is unclear whether management recommendations for the prairie falcon have direct relevance to these species.

The courtship behavior of the peregrine falcon, gyrfalcon, and prairie falcon are very similar, with at least 75% of the behaviors common to all (Wrege and Cade 1977), but they differ considerably in their ecology and habitat requirements (Brown and Amadon 1969). Both the peregrine falcon and gyrfalcon have been studied intensively (e.g., more than 1400 citations on the peregrine falcon were listed by Porter et al. 1987).

Most literature pertaining to the effects of human activities on peregrine falcons reports incidental observations of 1 or several nesting pairs in relation to an activity source (e.g., Fyfe and Olendorff 1976, White and Emison 1988). A notable exception is a study by Ritchie (1987) on the effects of maintenance activities along the Alaska pipeline on nesting peregrine falcons. Platt (1977) studied the impact of helicopter flight and observer disturbance near gyrfalcon aeries. Both found no detectable effects of human activities on the productivity of the falcons. Considerable individual variation, previous exposure to human activities (e.g., urban nesting peregrine falcons compared to those nesting in the arctic), and various, usually unknown biotic variables (e.g., prey abundance, weather conditions), may reduce the usefulness of these findings. There are, however, consistent trends in the behavioral reaction of peregrine falcons and gyrfalcons, which are similar to those of prairie falcons. Generally, the falcons are least tolerant of disturbance from pre-laying through incubation. Once young have hatched the falcons exhibit considerably higher levels of tolerance and are unlikely to abandon the nesting attempt (peregrine falcon: Cade 1960, Cade and White 1976, Fyfe and Olendorff 1976, Eberhardt and Skaggs 1977, Olsen and Olsen 1978, Monk 1980, Roseneau et al. 1981; gyrfalcon: Fyfe and

Olendorff 1976, Platt 1977, Roseneau et al. 1981; prairie falcon: Parker 1972, 1973, Fyfe and Olendorff 1976, Harmata et al. 1978, Becker and Ball 1983). Exposure to direct human persecution influences the reaction of a raptor to human activities and may make such birds much more sensitive to disturbances (Newton 1979). Construction activities, operation of heavy machinery, aircraft activity, all with the notable absence of direct human persecution, were generally tolerated by nesting peregrine falcons and gyrfalcons (Platt 1977, Ellis 1981, Haugh 1982, White and Thurow 1985, Ritchie 1987, White and Emison 1988). Taxonomic relatedness, as well as similarities in behavior and reaction to human disturbance activities suggest that the management recommendations based on this study may also be applicable to peregrine falcons and gyrfalcons, at least to nesting pairs previously exposed to some disturbance activities.

Management Recommendations For The BOPA

1). This study has documented that numbers of visitors to the BOPA are increasing. In light of this trend and the large number of problems related to visitor use noted in this study, I urge the BLM to initiate a review of all pertinent management documents.

2). Every prairie falcon nesting attempt in the Halverson Lake area failed. Failure rates in all other study locations were low. Therefore, it is not unreasonable to conclude that the failures that occurred at Halverson Lake may be related to intensive recreation in that area. I recommend that the BLM initiate a study to evaluate the relationship between falcon reproduction and recreation activities in the Halverson Lake area.

3). Observations made in the Dedication Overlook area strongly suggest that foot traffic on the old stagecoach road disturbs falcons nesting in this area. The stagecoach road should be permanently closed to all visitors.

4). This study emphasizes the importance of the raptor and prey monitoring program in the BOPA. Monitoring data were essential for evaluating falcon reproduction over time and explain trends in falcon reproduction with respect to prey densities. More complete monitoring data would have increased my analytical capabilities and further strengthened the conclusions drawn in this study. In light of the many problems (wildfires, grazing, recreation, military training) facing the BOPA, basic monitoring data are of critical importance to evaluate the effects of such activities on the reproductive performance of nesting raptors. I urge the BLM to renew its commitment to raptor and prey monitoring in the BOPA through a review of current monitoring procedures and implementation of yearly raptor and prey surveys.

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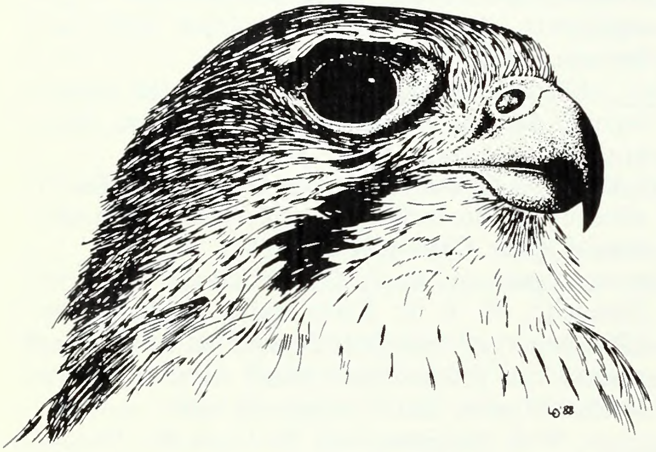
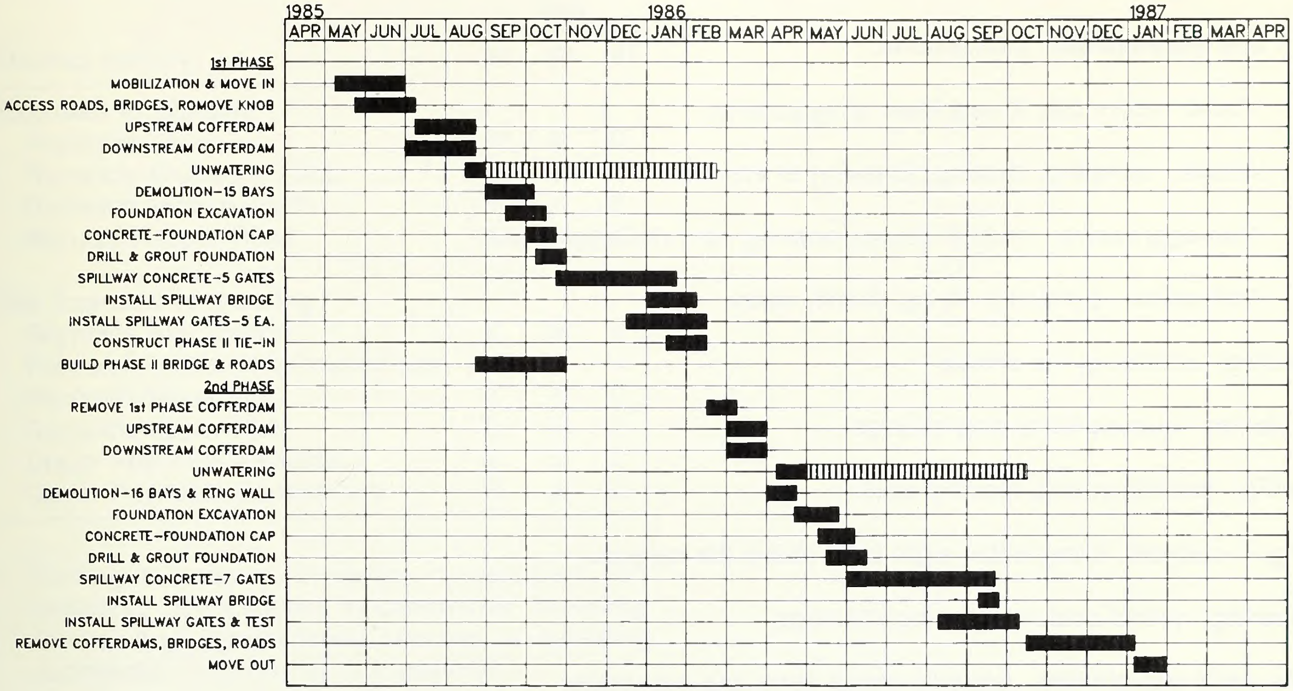


Appendix 1. Construction schedule for the Swan Falls Dam spillway, 1984-1987.



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Appendix 2. Definitions of behavior categories used in continuous behavioral observations of prairie falcons.

Absence: eggs or chicks are left unattended by both adults.

Inter- and Intra-specific Interactions:

- **Vocal:** alarm call, lowest level of aggression.
- **Attack:** stooping, chasing, following of intruder.
- **Non-aggressive:** mutual display, soaring, no overt aggression.
- **Defensive:** avoidance, flying directly away.

Brooding: sheltering the chicks.

Copulation: successful mating attempt.

Feeding: feeding young, feeding adult.

Flying-in-canyon: flying within sight in or above the canyon.

Incubating: prone posture covering the eggs.

Inside aerie out-of-view: falcon(s) inside aerie, but not visible.

Nest visit: adult entering the scrape for less than 1 min.

Out-of-canyon: out-of-sight and out-of-canyon (this category was used when the bird left the canyon).

Out-of-view: falcon is not in the nesting territory, but was not observed leaving the canyon.

Out-of-view in-canyon: falcon is obstructed from view for the observer, but is known to be in the nesting territory because of vocalizations or other indications of presence.

Patrolling: alternately gliding and flapping flight in front of the aerie confined to the boundaries of the nesting territory.

Perching: inactively perching, no head or body movements.

Preening: cleaning, oiling, positioning feathers.

Prey cached: prey is hidden in nesting territory, generally in a small cave or in a clump of vegetation.

Prey delivery: delivery of fresh prey item to the nesting territory.

Prey retrieved: prey retrieved from a cache in the nesting territory.

Relocation: short flight (< 1 min) from one perch location to another.

Appendix 3. Occupancy of prairie falcon nesting territories in the blasting study location, 1985-1987.

	Year		
Nesting territory	85	86	87
Exposed to Blasting			
Reynolds Lower	4*	4	0
Reynolds Midcanyon Cup	4	4	0
Reynolds Midcanyon Pt	4	1	0
Reynolds-Upper Road	4	4	4
Not Exposed to Blasting			
Reynolds Exp Station	2	5	4
Reynolds Midcanyon Downstream	5	1	4
Reynolds Mouth	2	4	0
Reynolds-Upper-West	0	5	2
Upper Reynolds Backside	2	0	2
Upper Reynolds Downstream	2	4	0

* Coding occupancy: 0=vacant; 1=occupied non-breeding; 2=occupied undetermined breeding; 3=breeding undetermined success; 4=breeding successful; 5=breeding unsuccessful.

Appendix 4. ANOVA to test for differences in behaviors of male and female prairie falcons (expressed as percentages of total observation time per half-day) as determined by observations made in and outside a blind on (A) mornings and (B) afternoons for the pre-incubation ($n = 6$), incubation ($n = 12$), and brood-rearing ($n = 11$) stages at the Priest Upper nesting territory, 1986 and 1987.

A. Morning (male)

	Pre-incubation			Incubation			Brood-rearing		
Variables	F	P	r^2	F	P	r^2	F	P	r^2
Perching	0.11	0.75	0.02	0.16	0.69	0.01	0.07	0.79	0.01
Incubating	0.51	0.51	0.11	0.02	0.89	0.001	-	-	-
Brooding	-	-	-	-	-	-	2.08	0.19	0.22
Canyon flight	-	-	-	-	-	-	0.33	0.58	0.04
Out-of-view	0.15	0.71	0.03	0.02	0.89	0.001	0.03	0.87	0.001
Out-of-view in-canyon	0.07	0.81	0.01	0.10	0.76	0.01	5.35	0.05	0.43
Out-of-canyon	0.95	0.38	0.19	2.63	0.13	0.20	2.52	0.15	0.26
Hotelling-Lawley Trace		-			$F = 0.83$ $P = 0.57$			$F = 1.31$ $P = 0.49$	

B. Afternoon (male)

	Pre-incubation			Incubation			Brood-rearing		
Variables	F	P	r^2	F	P	r^2	F	P	r^2
Perching	0.01	0.92	0.002	0.91	0.36	0.08	0.28	0.61	0.03
Incubating	0.09	0.95	0.001	0.53	0.48	0.05	-	-	-
Brooding	-	-	-	-	-	-	0.76	0.41	0.09
Canyon flight	-	-	-	-	-	-	0.41	0.54	0.05
Out-of-view	0.18	0.68	0.04	1.42	0.26	0.12	0.65	0.44	0.08
Out-of-view in-canyon	0.07	0.81	0.01	0.56	0.47	0.05	0.001	0.97	0.001
Out-of-canyon	0.06	0.82	0.01	1.19	0.30	0.10	0.62	0.45	0.08
Hotelling-Lawley Trace		-			$F = 0.67$ $P = 0.66$			$F = 0.56$ $P = 0.75$	

Appendix 4. *continued*

A. Morning (female)

	Pre-incubation			Incubation			Brood-rearing		
Variables	*F*	*P*	r^2	*F*	*P*	r^2	*F*	*P*	r^2
Perching	0.51	0.51	0.11	0.22	0.65	0.02	6.71	0.03	0.48
Incubating	0.16	0.70	0.03	0.36	0.56	0.03	-	-	-
Brooding	-	-	-	-	-	-	1.72	0.23	0.19
Canyon flight	-	-	-	-	-	-	0.28	0.61	0.03
Out-of-view	0.21	0.67	0.04	0.44	0.52	0.04	0.30	0.59	0.04
Out-of-view in-canyon	1.00	0.37	0.20	0.36	0.56	0.03	0.81	0.39	0.10
Out-of-canyon	0.31	0.60	0.07	0.06	0.81	0.005	0.58	0.47	0.07
Hotelling-Lawley Trace		-			$F = 0.11$ $P = 0.98$			$F = 1.29$ $P = 0.49$	

B. Afternoon (female)

	Pre-incubation			Incubation			Brood-rearing		
Variables	*F*	*P*	r^2	*F*	*P*	r^2	*F*	*P*	r^2
Perching	5.39	0.08	0.57	0.41	0.53	0.03	1.72	0.23	0.19
Incubating	0.001	0.94	0.001	0.52	0.48	0.04	-	-	-
Brooding	-	-	-	-	-	-	0.35	0.57	0.04
Canyon flight	-	-	-	-	-	-	1.09	0.33	0.13
Out-of-view	0.22	0.66	0.05	0.47	0.50	0.04	0.22	0.65	0.03
Out-of-view in-canyon	1.00	0.37	0.20	-	-	-	1.66	0.23	0.19
Out-of-canyon	0.38	0.57	0.08	0.71	0.41	0.06	0.39	0.55	0.05
Hotelling-Lawley Trace		-			$F = 0.67$ $P = 0.63$			$F = 0.34$ $P = 0.86$	

Appendix 5. ANOVA to test for differences in behaviors of male and female prairie falcons (expressed as counts per half-day) as determined by observations made in and outside a blind on (A) mornings and (B) afternoons for the pre-incubation ($n = 6$), incubation ($n = 12$), and brood-rearing ($n = 11$) stages at the Priest Upper nesting territory, 1986 and 1987.

A. Morning (male)

	Pre-incubation			Incubation			Brood-rearing		
Variables	*F*	*P*	r^2	*F*	*P*	r^2	*F*	*P*	r^2
Patrolling	1.99	0.23	0.33	0.61	0.45	0.05	4.08	0.08	0.36
Aggression	2.89	0.16	0.41	2.06	0.18	0.17	0.87	0.38	0.11
Relocation	3.99	0.11	0.49	0.94	0.35	0.08	<0.001	0.99	<0.001
Prey delivery	<0.01	0.99	<0.001	0.25	0.62	0.02	0.13	0.72	0.01
Hotelling-Lawley Trace		$F = 0.50$ $P = 0.76$			$F = 0.47$ $P = 0.75$			$F = 0.73$ $P = 0.61$	

B. Afternoon (male)

	Pre-incubation			Incubation			Brood-rearing		
Variables	*F*	*P*	r^2	*F*	*P*	r^2	*F*	*P*	r^2
Patrolling	0.04	0.85	0.01	1.60	0.23	0.13	3.07	0.12	0.30
Aggression	0.001	0.96	0.001	1.67	0.22	0.14	1.45	0.26	0.17
Relocation	1.00	0.37	0.20	0.69	0.42	0.06	0.03	0.86	0.001
Prey delivery	0.14	0.72	0.03	0.02	0.90	0.001	1.16	0.31	0.14
Hotelling-Lawley Trace		$F = 0.58$ $P = 0.74$			$F = 1.44$ $P = 0.31$			$F = 0.93$ $P = 0.52$	

A. Morning (female)

	Pre-incubation			Incubation			Brood-rearing		
Variables	*F*	*P*	r^2	*F*	*P*	r^2	*F*	*P*	r^2
Patrolling	1.00	0.37	0.20	0.64	0.44	0.05	0.95	0.36	0.11
Aggression	0.66	0.46	0.14	1.82	0.20	0.15	1.02	0.34	0.12
Relocation	1.00	0.37	0.20	-	-	-	0.78	0.40	0.10
Prey delivery	1.00	0.37	0.20	0.69	0.42	0.06	0.17	0.68	0.02
Hotelling-Lawley Trace		-			$F = 0.60$ $P = 0.63$			$F = 1.01$ $P = 0.49$	

B. Afternoon (female)

	Pre-incubation			Incubation			Brood-rearing		
Variables	*F*	*P*	r^2	*F*	*P*	r^2	*F*	*P*	r^2
Patrolling	-	-	-	0.06	0.81	0.005	3.09	0.12	0.30
Aggression	1.18	0.33	0.22	0.07	0.79	0.006	0.12	0.73	0.01
Relocation	1.00	0.37	0.20	-	-	-	0.05	0.83	0.001
Prey delivery	-	-	-	0.69	0.42	0.06	1.87	0.21	0.21
Hotelling-Lawley Trace		$F = 0.70$ $P = 0.56$			$F = 0.83$ $P = 0.51$			$F = 1.10$ $P = 0.46$	

Appendix 6. Occupancy of prairie falcon nesting territories in the BOPA study locations, 1973-1987.

	Year														
Nesting territory	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87
Construction															
Falcon Flats Black Rock	2[2]	-	2	4	4	4	0	5	4	2	2	3	2	5	0
Falcon Flats Fingers[3]	2	-	-	3	4	3	0	0	2	2	2	4	4	5	4
Ferry	2	-	-	4	2	0	-	0	2	-	0	4	5	0	0
Swan Dam Road S Side	-	-	-	0	2	0	0	0	0	-	-	0	0	0	4
Swan Dam Road Turn[3]	2	4	-	4	3	2	2	-	-	0	4	4	0	4	0
Swan Dam Three Poles[3]	-	4	2	4	0	0	5	2	2	4	4	4	4	0	4
Swan Road N Side[3]	2	-	4	4	4	4	2	4	-	2	3	4	4	4	4
Recreation															
Camera	4	-	4	3	5	3	4	4	4	4	2	4	4	4	4
Dedication Point	2	-	3	3	2	2	4	2	4	2	4	4	4	2	4
Dedication Site	2	4	4	2	3	2	2	4	3	4	5	0	4	5	4
PF I	2	2	4	4	4	2	0	0	2	5	4	4	4	0	0
PF II	2	-	4	4	4	2	0	2	2	2	0	4	4	5	4
Priest Rapids I	2	2	2	3	2	4	2	0	2	-	-	5	4	5	4
Priest Upper	2	4	4	4	4	4	2	2	4	4	2	4	4	4	4
Halverson Dunes	2	-	4	0	4	2	2	-	2	2	-	-	-	-	5
Halverson Trail	4	4	3	4	4	5	0	-	4	4	2	-	-	-	5
Halverson Upper Lake[4]	-	-	-	2	0	0	-	-	-	-	-	-	-	5	-
Control															
Tick	-	-	-	0	0	0	-	0	0	0	2	0	0	0	0
Tick City	-	-	-	0	0	0	-	2	5	5	2	2	4	0	5
Tick New	-	-	-	0	0	0	-	0	0	0	0	4	0	0	0
Tick I	5	4	4	4	4	4	2	4	2	4	4	2	0	4	0
Tick II	3	4	4	4	5	4	2	4	4	3	2	2	4	4	4
Tick III	5	0	4	4	3	1	5	4	2	4	2	2	4	4	5
Tick IV	-	-	-	4	4	0	1	0	4	4	3	2	0	0	0
Red Trail	2	2	4	3	2	4	4	2	2	3	2	2	4	4	4
San Sebastian Basin	-	-	-	0	0	2	0	2	0	4	3	3	-	5	4

1) Only in the years 1976, 1977, and 1978 were the 3 study locations completely surveyed; only these years were used to calculate occupancy rates.

2) Occupancy coding: - = not surveyed; 0 = vacant; 1 = 1-bird site; 2 = occupied undetermined breeding; 3 = breeding undetermined success; 4 = breeding successful; 5 = breeding unsuccessful.

3) Nesting territories located along the Swan Falls access road.

4) Unpublished data Bureau of Land Management, Boise, Idaho.

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